COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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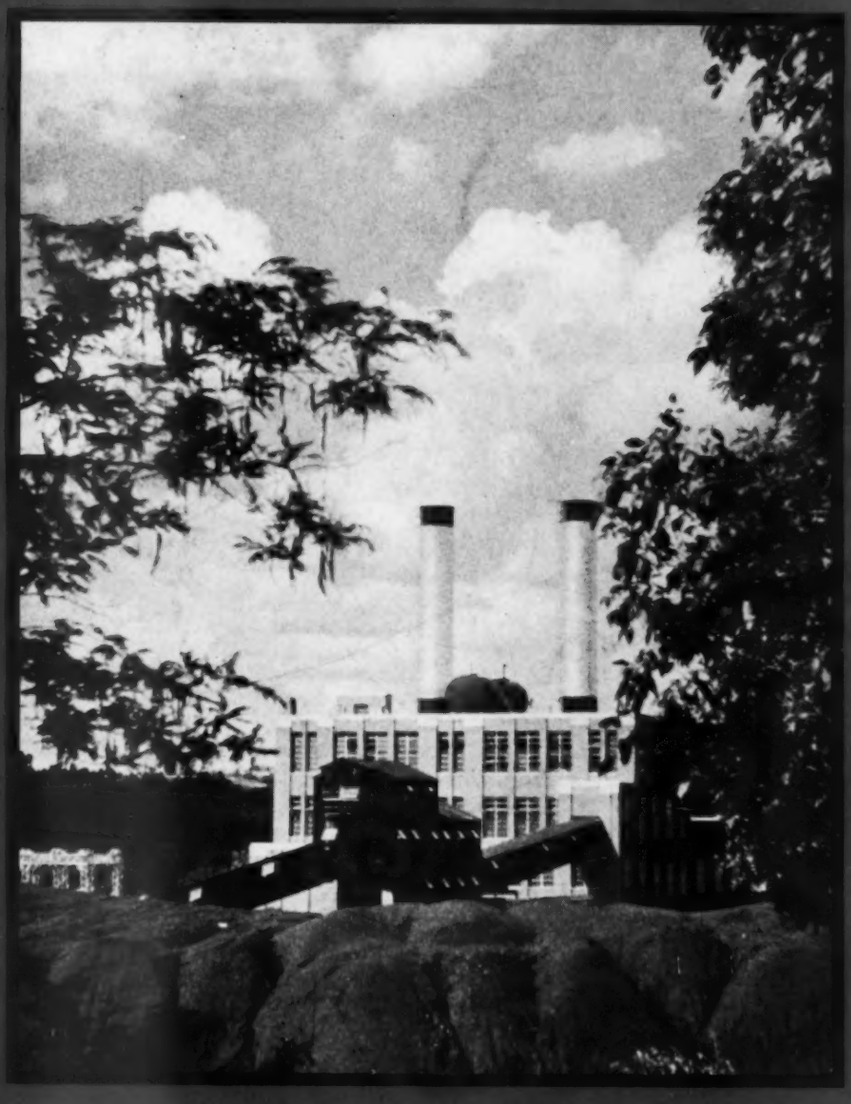


Cliffside Station, Duke Power Company

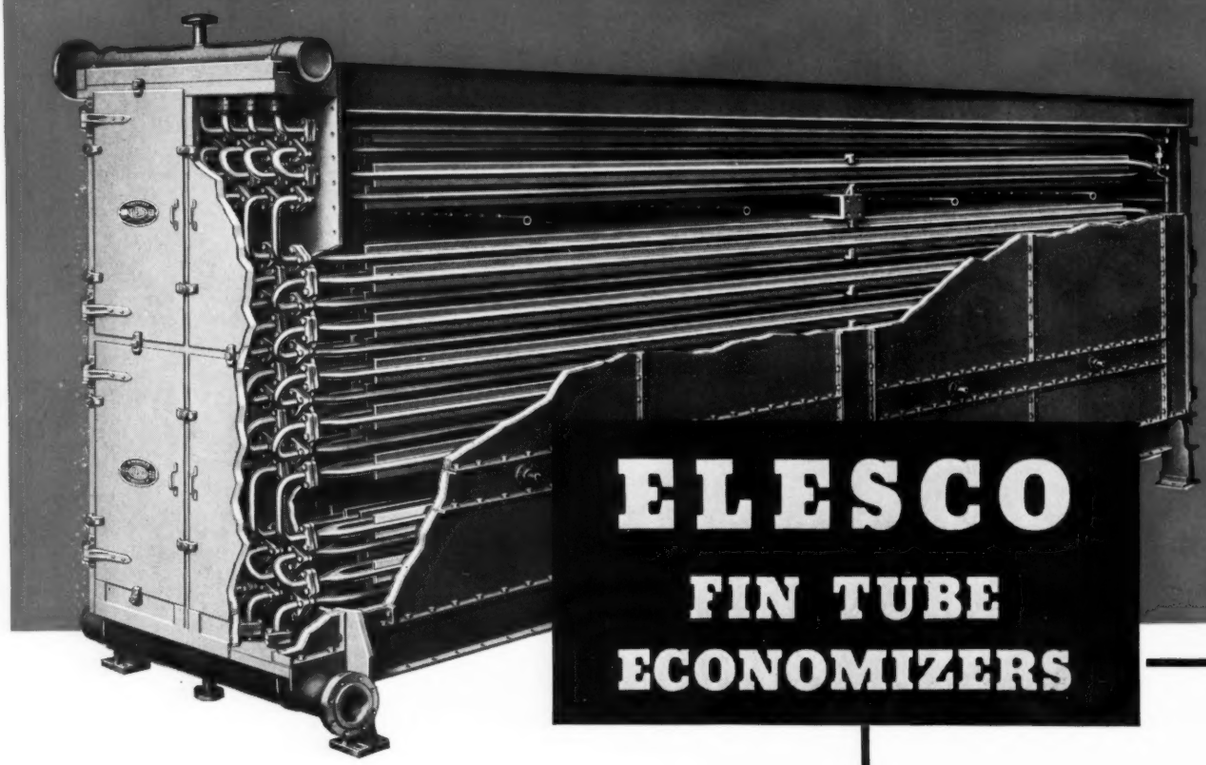
More Power for Piedmont Carolinas at Cliffside

Economy in Boiler-Water Recirculation

Enthalpy and Entropy

The First and Second Laws of Thermodynamics

For high heat recovery



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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME TWELVE NUMBER FOUR

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EDITORIAL

Questionable Precautions

It is understood that for the past year British engineering periodicals have been enjoined from printing anything descriptive of power stations, on the assumption that such information would be helpful to the enemy. At first glance this seems a wise precaution when a country is at war, particularly as concerns those power plants which are a part of munitions factories, where such descriptions might fix the location and indicate the magnitude of the undertaking. As to central stations, however, it is axiomatic that enemy agents know their locations, the areas served and their relative importance; technical details as to their equipment matter little. Presumably, such stations are plotted on military maps, as objectives, and their stacks are readily distinguishable from the air. This is borne out by the recent bombing of the Klingenberg Station in Berlin by the R.A.F.

Although this country is not at war, the preparedness program and the necessity for guarding against "Fifth Column" activities have already been responsible in some quarters for the imposition of restrictions, not only as to published information on some recent power plant installations, but also as to their visitation by recognized groups of engineers whose loyalty can readily be checked.

While every precaution against sabotage must be taken at the present time, the real danger from this source usually lies in subversive influences *within* a plant rather than from without. The presence of uniformed guards and rigid enforcement of passes serve not only to keep out undesirables but also exert a psychological influence on those working within a plant. This is especially true when construction is in progress and workers other than the regular operating crew are involved.

However, the publication or the non-publication of technical literature concerning any station is most unlikely to have any bearing on its protection. As a matter of fact, such information as might possibly be useful to a potential enemy, in the form of lists, essential data and maps showing transmission systems and areas served, is already in print and procurable both from private sources and from the government itself.

When one reflects on the recent widely publicized remarks of a high ranking army officer who divulged in full detail our requirements and shortcomings of materiel, or on that which has been revealed on the floor of Congress, the fears of some concerning power plants fade into insignificance.

In such times as the present, sweeping decisions from the top, if unsusceptible to modification or interpretation to meet circumstances, are likely to serve no useful purpose. This is especially true when they emanate from governmental agencies unfamiliar with all the facts.

Is Your Power Plant Ready?

Popular belief that appropriations by Congress and our much-vaunted industrialization are the complete answer to preparedness, is now gradually giving place to a realization that there are many other factors likely to stand in the way of early attainment of the objective. Aside from the controversial questions of organization, profits and labor, of which one reads so much in the daily press, there are potential bottlenecks involving the creation of facilities, plant extensions, machine tools, gages and the securing of experienced men to handle the multitude of problems. This applies not alone to those firms which have received or are likely to receive Government orders but also to the far greater number who are indirectly involved in supplying materials and equipment to such firms. Back of it all lies the necessity for an adequate and dependable supply of power.

In so far as concerns purchased power, the utilities are now apparently in a strong position to meet their industrial power demands and, as a result of extensions now being made or projected, to keep pace with the growth in this demand.

Among those firms which generate their own power, and to which Government orders have been allocated, the situation appears to be well in hand. However, there are many others, particularly the smaller firms, who in the course of the next year may be called upon to contribute either directly or indirectly to the defense program, and it behooves them now to survey their power facilities and to rectify any weak spots. To put off doing so may cause embarrassment later if it becomes necessary to invoke widespread priorities. In fact, priority orders have already appeared to a limited extent.

An industrial power plant which has been functioning satisfactorily under normal load conditions may be found wanting when called upon to carry a sustained peak load in a situation that does not permit the usual outage for overhaul or repairs. This occurred in many cases during the World War and is likely to be repeated in the present emergency. The difficulties may lie in obsolete equipment, in inadequate reserve or in the functioning of minor accessories. Furthermore, despite efforts to the contrary, there is certain to be some loss of trained operating personnel—men who could be depended upon to keep a unit running in an emergency, but without whom a failure in equipment might be fatal to production.

Therefore, while there is still time every effort should be made to assure that your plant is fully capable of meeting all probable demands.

MORE POWER for PIEDMONT CA

By EDWARD E. WILLIAMS

Gen'l Supt. of Steam Plants,
Duke Power Co., Charlotte, N. C.

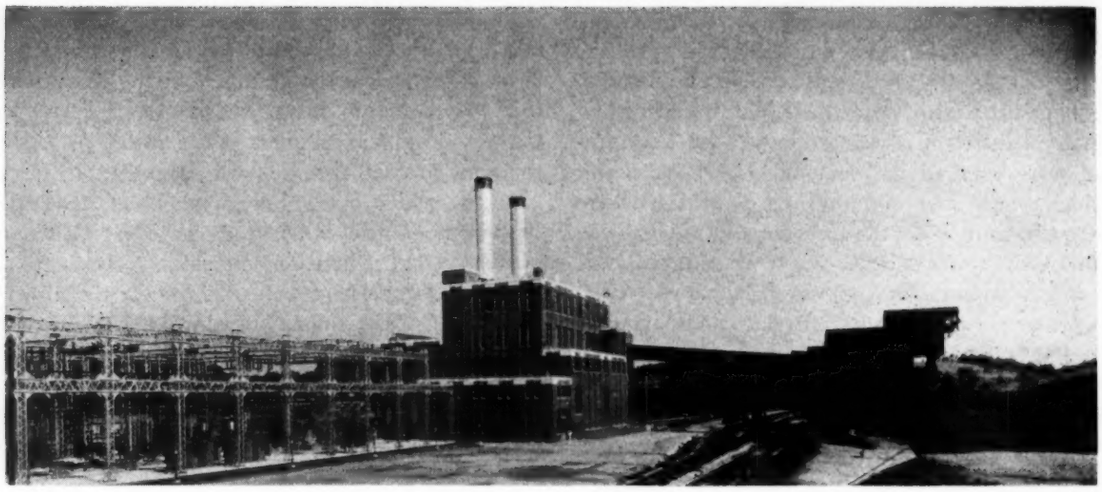


Fig. 1—Exterior view of Cliffside Station

THE Piedmont Carolinas comprise that rolling section of the industrialized Southland, extending from the sandhills on the east to the foothills of the Appalachian Range in the west, with its axis and main traffic artery running parallel to the course of these mountains across North and South Carolina. Endowed with a mild healthful climate, fertile fields, excellent water supplies, adequate transportation facilities and ample supply of efficient home-grown labor, this section with a population of 2,500,000 is the industrial center of the Carolinas, and the power supply for its mills, factories, homes and farms is most important.

Industrialization, which began in earnest shortly after the dawn of this century, has progressed to the point where the Piedmont Carolinas now have:

1. Over seven million spindles in textile mills.
2. Two hundred hosiery mills.
3. Tobacco factories that produce fifty per cent of the total cigarettes manufactured in this country.
4. The largest furniture manufacturing center outside of Grand Rapids, Mich.

Even with the extensive industrialization that has taken place during the past two or three decades, the Piedmont Section is essentially rural. Large factories have been built along the country side, drawing labor from neighboring farms and villages and creating their own towns or villages. Kannapolis, N. C., home of the largest towel mills in the world, is an unincorporated town. Charlotte, largest city of the two Carolinas, has a population of only 101,300. So it goes throughout Piedmont, one mill after another, but few large centers of population.

This condition is also evidenced by the power demand. The bulk of power generated for this section is used by industry. Electrical merchandising campaigns and rural electrification sponsored by the utilities have

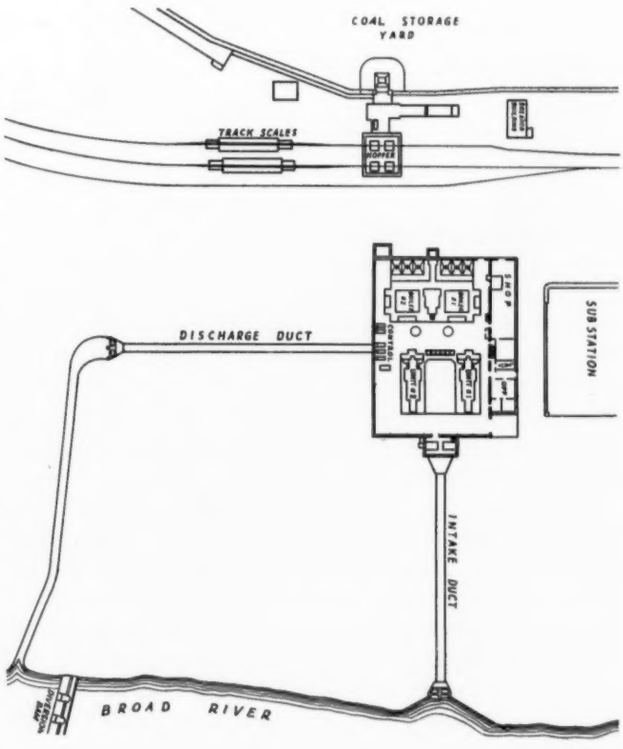


Fig. 2—Plan of power house, substation and coal-handling layout

CAROLINAS at CLIFFSIDE

A description of the 80,000-kw first section of Cliffside Steam Station of the Duke Power Company, in which the selection of site, initial capacity in relation to system capacity, unit arrangement and the details of design are discussed.

affected the percentages, but the industrial power demand still accounts for over seventy per cent of the utility power sold.

Extension of Power Facilities

Power sales (kwh) in this area have increased over sixty per cent since 1935. To meet the increasing power demand and insure its customers against any power shortage, due to deficiency of rainfall on the watersheds of its extensive hydro-electric system, the Duke Power Company, principal utility serving this section, began extending its steam power generating capacity in 1936. The 55,000-kw addition to Riverbend Steam Station was completed and placed in operation in July 1938.[1] Construction work was started on the 80,000-kw first section of Cliffside Steam Station in January 1939, and the station was placed in operation in July 1940. An exterior view is shown in Fig. 1.

Cliffside Steam Station is located at the junction of the Broad and the Second Broad rivers, twelve miles southwest of Shelby, North Carolina. This location was selected for the following reasons:

1. Availability of necessary condensing water for the projected development.
2. The transmission lines necessary to tie-in with the system would definitely strengthen the system layout as a whole.
3. A steam power station located at this point would be in an excellent position to provide and safeguard service to near-by load centers.
4. The proximity of adequate railway lines leading to desirable coal fields.

Rail connection to the plant is by means of a seven-mile spur to the main line of the Clinchfield Railroad. Rail distances to the coal fields are, 235 miles to St. Charles, Va.; 250 miles to La Follette, Tenn.; 304 miles to the eastern Kentucky fields; and 303 miles to the low-volatile field of West Virginia.

It is therefore apparent that a wide variety of coals is available to Cliffside. As it is extremely unlikely that it will be possible or even desirable to purchase the station requirements from any one source, it follows that the plant will be required to operate on a general mixture made up of coals with the following extreme variations in analyses:

Volatile	18 to 39 per cent
Ash	4 to 15 per cent
Fusion point	2100 to 2900 F
Grindability	35 to 100
Btu per lb	12,500 to 15,000

While these fuel characteristics materially influenced certain features of the design and the selection of equipment, the principal factors determining the major elements of the station design were:

1. The decision to install 80,000 kw in steam-generating capacity to keep pace with the system power demand.

[1] See "Duke Power Company Adds 55,000 kw at Riverbend," *Southern Power Journal*, October 1938.

Fig. 3—Turbine room with boilers in background, showing absence of curtain wall

2. The selection of a site allowing an ultimate development of 240,000 kw capacity.
3. The adoption of an average annual capacity factor of 40 per cent as the basis of economic design.

Consideration of these factors resulted in the design of the 80,000-kw first section of an ultimate 240,000-kw development at Cliffside, with steam conditions for this first section established as 825 lb gage pressure and 900 F at the turbine throttle.

Station Layout

The general plan of the power house, substation and coal-handling structures is shown in Fig. 2 and a cross-section of the station in Fig. 4. Interesting features of this layout are:

1. An individual intake structure for each section of the power house.
2. Location of service facilities, offices and storerooms in the upstream or permanent end of the power house.
3. Absence of a curtain wall between turbine room and boiler room; see Fig. 3.
4. Two 40,000-kw turbine-generator units.
5. One steam generator per turbine.

Use of individual intake structures for the power house sections was determined by economic considerations involving the power-house and substation layout, river characteristics and foundation soundings. The customary curtain wall between the boiler room and turbine room was omitted in order to provide better visibility from the central control board and greater accessibility of equipment for operation and maintenance purposes. Experience at other stations on the system has indicated that while the curtain wall gives the turbine room a more finished appearance it sacrifices desirable light in the boiler room. Omission of this wall has made possible the compactness and daylight attractiveness of the station interior.

Two 40,000-kw turbine-generator units were installed instead of one 80,000-kw unit in order to provide greater flexibility in operation of the station as an auxiliary to the hydro system.

Decision to use one steam generator per turbine-generator was based on experience at Riverbend Station where units of similar design have established availability records that justify the elimination of spare boiler capacity.

Steam-Generating Units and Firing Equipment

The two steam-generating units are each rated at 375,000 lb per hr, with a maximum capacity of 400,000 lb per hr. Each consists of boiler, furnace, superheater and air preheater; this arrangement, without an economizer, being preferred for the established operating conditions so long as justified efficiencies can be obtained. The design selected lends itself readily to protection against corrosion during long standby periods, which is an important consideration in view of the estimated annual operation

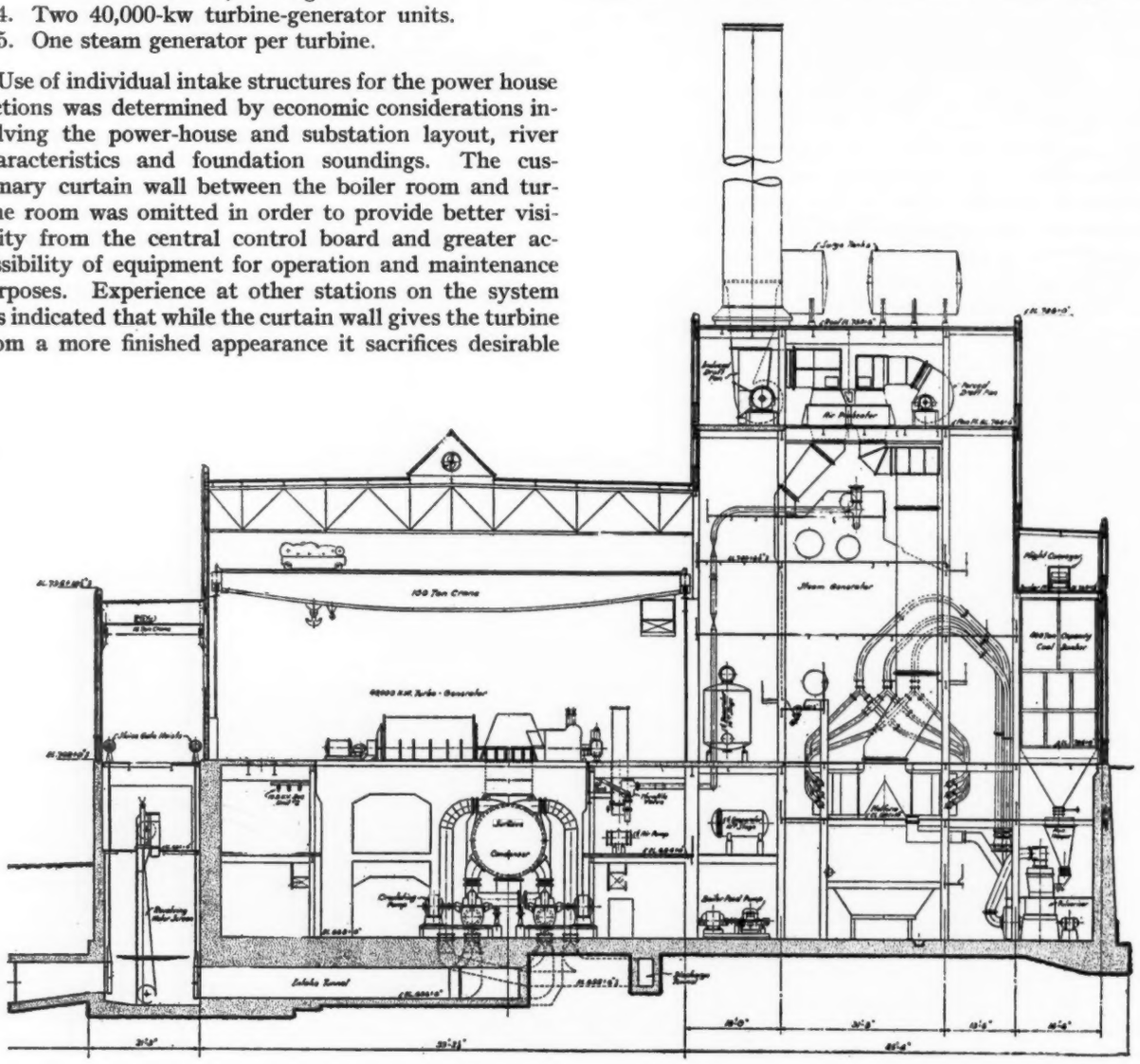


Fig. 4—Sectional elevation of power house

of 3500 hr. A section through one of steam-generating units is shown in Fig. 5.

The boilers are of the four-drum, bent-tube type, designed for 900-lb pressure. Drums are of fusion-welded construction, the upper front and bottom drums being 48 in. inside diameter, the upper rear drum 60 in., and the dry drum 36 in. inside diameter. Completely water-cooled furnaces of fin-tube design with a water-screen dry bottom are provided. The furnaces are arranged for tangential firing, each corner burner assembly having three coal nozzles. Each nozzle is supplied by one of the three pulverizer mills, making a total of twelve burners per boiler. They are equipped with retractable oil torches for lighting off with 40–55 S.S.U. fuel oil. The furnaces are designed for a heat liberation of 24,800 Btu per cu ft per hr, and a gas temperature of 2040 F entering the first row of boiler tubes in front of the superheater at 375,000 lb per hr actual evaporation.

The superheaters, of the continuous-loop type, are located interbank as shown in Fig. 5. They are designed for 900 F. total steam temperature at 310,000 lb per hr output, the steam temperature at higher ratings being controlled by means of motor-operated superheater bypass dampers. Regenerative type air preheaters are employed, and the double-inlet forced- and induced-draft fans are driven by constant-speed motors through hydraulic couplings. Pulverizing equipment serving each steam generator consists of three bowl-type mills with integral exhausters and cage-type feeders. The mills are driven by constant-speed motors. Continuous capacity ratings based on 10 per cent moisture coal are as follows:

50 per cent grindability coal.....10 tons per hr
30 per cent grindability coal..... 8.5 tons per hr

Two mills have ample capacity for normal full-load operation of one unit, thus allowing the outage of one mill for maintenance purposes without interfering with station output.

Coal from overhead bunkers passes through auxiliary hoppers atop the pulverizer mill feeders, thence to the mills and furnaces. The $2^1/_2$-ton capacity auxiliary hoppers interposed between the coal bunker and mills serve as a safeguard against interruption of coal feed to the mills when handling wet slack coal. These hoppers are watched by electric eyes arranged to operate an alarm in case of stoppage of coal feed from the bunkers.

Turbine-Generators

Each steam-generating unit is piped direct to its corresponding turbine-generator unit, but a cross-over connection is provided so that either boiler may serve either turbine. The turbine-generators are rated 40,000 kw at 80 per cent power factor, with overload rating of 50,000 kw at 95 per cent power factor. The turbines are 20-stage tandem-compound impulse type, designed for operation at 3600 rpm with steam at 825 lb pressure and 900 F. Turbines and generators are connected by rigid couplings. The latter are equipped for normal operation with hydrogen cooling, but are also designed to carry a continuous load of 35,000 kw at unity power factor with air cooling. The main exciter and pilot exciter are driven from the generator shaft through a reduction gear.

Oil-pressure pipes supplying the bearings of the units are carried inside the oil drain lines, and the high-pressure governing mechanism is located inside the oil tank, these features being incorporated in the design to minimize the danger from oil fires. The following recording supervisory instruments are provided with each unit:

1. Speed and camshaft position.
2. Vibration amplitude.
3. Shaft eccentricity.

Condensers and Auxiliaries

Each turbine-generator unit is served by a cylindrical steel-shell surface condenser of the two-pass divided water-box type. A cross-over connection between the discharge lines of the two circulating pumps of each unit makes it possible to supply the entire condenser by one pump during cold water periods. Two condensate pumps are also provided for each unit. Duplicate tube jet air pumps with inner after-condensers are furnished with each condenser, one pump unit being ample for normal operating conditions.

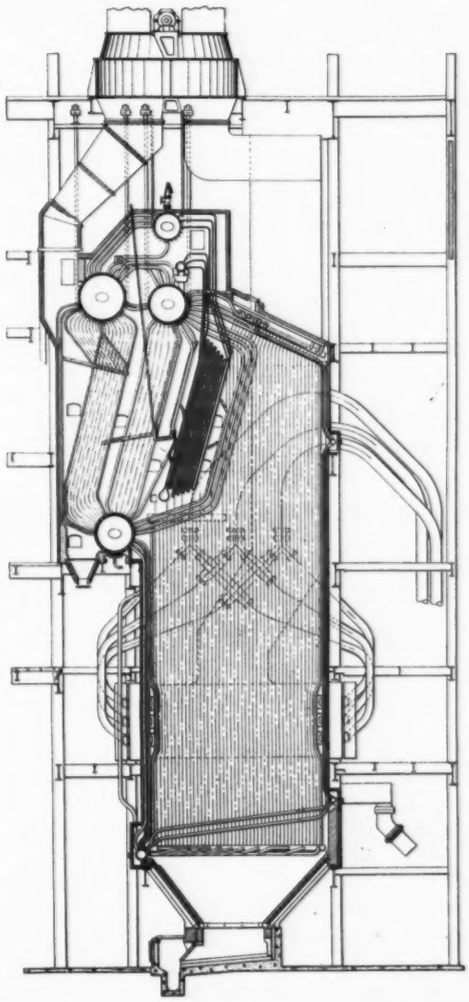


Fig. 5—Section through one of the steam generating units, from a preliminary drawing

Condensate from the main condensers is returned to the boilers through three condenser-type closed heaters and a deaerator which also serves as a heater. These

heaters are fed with steam extracted from the turbine, as shown in the typical heat-balance diagram, Fig. 6. The deaerators are guaranteed to deliver water with zero oxygen content, and the evaporators to produce vapor containing not more than 0.25 gr per gallon of solid mineral impurities. With the low makeup required for this type of operation, delivering oxygen-free feedwater to the boilers and maintaining extremely low total solids in the boiler water have made possible the very highly satisfactory operating experience of existing boiler units on the Duke System without resorting to chemical treatment of feedwater.

There are four boiler-feed pumps, each having sufficient capacity to supply one steam-generating unit. Three of these pumps are driven by 3600-rpm constant-speed motors and the fourth by a direct-connected steam turbine. Information regarding the service pumps and miscellaneous station auxiliaries is contained in the accompanying list of principal equipment.

All switching for 13.2 kv and above and all main and auxiliary transformers are located in an outdoor switching station. Particular attention was given to the mitigation of fire hazard by wide spacing of equipment and by the installation of remote-control spray systems for the various transformers. To limit further the spread of oil from damaged equipment, the entire switching station area was waterproofed, provided with an adequate drainage system, and then covered with pebbles to a depth of 18-in.

The boiler control board and the main switchboard have been located together along the temporary wall of the power house and in line with the turbine end of No. 2 turbine-generator unit. Location of the control boards at this point, with provision for extension as the power-house sections are added, establishes centralized control of boiler plant, turbine-generators and substation. A view of these control boards is shown in Fig. 8.

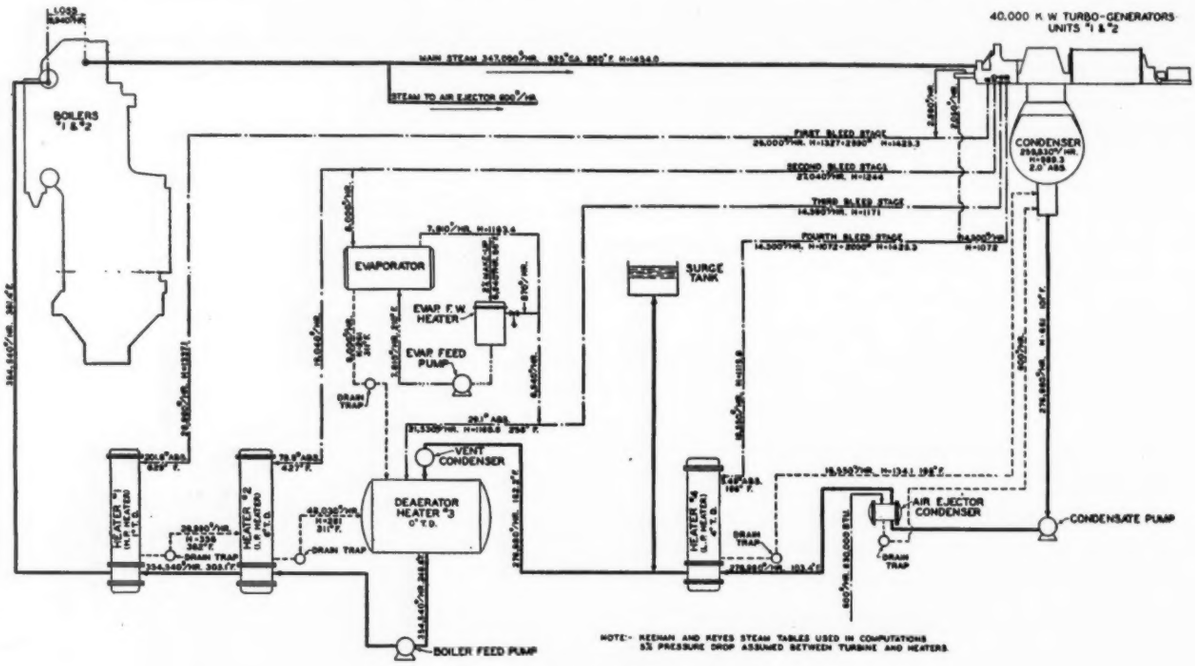


Fig. 6—Heat-balance diagram

Electrical System and Controls

Each of the 40,000-kw 80-per cent power factor generators has voltage-regulating equipment for high-speed excitation. Generation from each unit is transmitted into the 100- and 44-kv system networks through two 25,000-kva, three-phase, forced oil-cooled transformers. Provision is made to change two of the transformers, and their bus connections, for either 100-kv star or 44-kv delta operation by interlocked disconnecting switches.

All major auxiliaries, with the exception of one steam-driven boiler-feed pump, are driven by constant-speed 550-volt induction motors controlled by electrically operated, steel-enclosed, withdrawal-type air circuit-breakers. The auxiliaries for each unit and its boiler are supplied by a transformer bank connected between the generator and its step-up transformers, essential station auxiliaries being arranged for automatic transfer to any of three available sources of power supply.

It will be observed that both the electrical switchboard and the boiler control board are of the benchboard type, and that a rather unique arrangement of the boiler meters on top of the boiler benchboards allows the desired visibility of the vertical panels behind the benchboards. Complete controls for one boiler are located on one 4-ft wide benchboard section, with controls for the corresponding turbine-generator unit on a similar switchboard unit directly across the operator's aisle.

All boiler operations except lighting off are controlled from the boiler control boards. Controls necessary for lighting off burners are arranged on benchboards located in the aisle between the boilers, overlooking the pulverizing mills. Communication between these boards and the main control boards is maintained by means of illuminated signals during the lighting off operation.

Combustion is controlled manually by the operator, but controls are arranged so that automatic combustion-control equipment can be readily installed when such

Fig. 7—Pump room showing typical auxiliary electrical controls

installation is considered justifiable by the savings to be effected.

Coal and Ash Handling

Coal cars arriving at the plant are placed on the two tracks leading to the unloading hopper. The cars are weighed on track scales located just ahead of the unloading hopper, a scale house between the tracks housing the beams of both track scales. Cars are unloaded manually, two at a time, over the unloading hopper. The coal is removed from this hopper by means of four shaker feeders discharging onto a 36-in., 300-ton-per-hour conveyor belt. From this point the coal travels by means of belt conveyors to the crusher house, thence to the junction house from which point it is delivered to storage or to the power-house bunker room. In the bunker room it is distributed to the two 400-ton capacity bunkers over the pulverizers by means of a scraper conveyor. In reclaiming from storage, coal passes from the reclaiming hopper to the crusher house, thence to the junction house and to the power-house bunker room. Weighing of coal delivered to the bunkers is accomplished by means of a weightometer on the belt conveyor between the junction house and the power house. A magnetic pulley on the power-house end of this belt removes tramp iron from the coal.

Coal is stored by means of a single 8-cu yd cable drag scraper, on a field having an area of 225,000 sq ft. The complete storage and reclaiming equipment, including scraper bucket, double-drum scraper hoist and motor-driven tail tower, is operated from a control tower located immediately above the reclaiming hopper.

The ash-disposal system consists essentially of a sluice-way under the ash hoppers which discharges into an outdoor ashpit. Water and fines which fall through the sloping screen of this pit are pumped to a ravine below the plant. Large clinkers are removed from the pit by means of an overhead crane with the clamshell arranged to load these clinkers into cars or trucks.

Service Facilities

The station service facilities are housed in the first bay of the power house, on two floors below and one above ground level. Storerooms for repair parts and supplies are provided in the available space on the two lower levels, while the Superintendent's and clerk's offices, first aid room, visitor's lavatory and shop occupy this bay at ground level. The laboratory, production office, conference room and main locker and wash rooms are on the second floor. An elevator installed along the inner wall near the center of this bay provides ready access to all floor levels.

An operators' village has been erected on the crest of a hill overlooking the power-house site. Twenty six-room and twenty-two five-room modern frame cottages have been provided for the members of the station operating crew and their families. There is also one eight-room dormitory for single men. The village has been attractively landscaped, and is equipped with

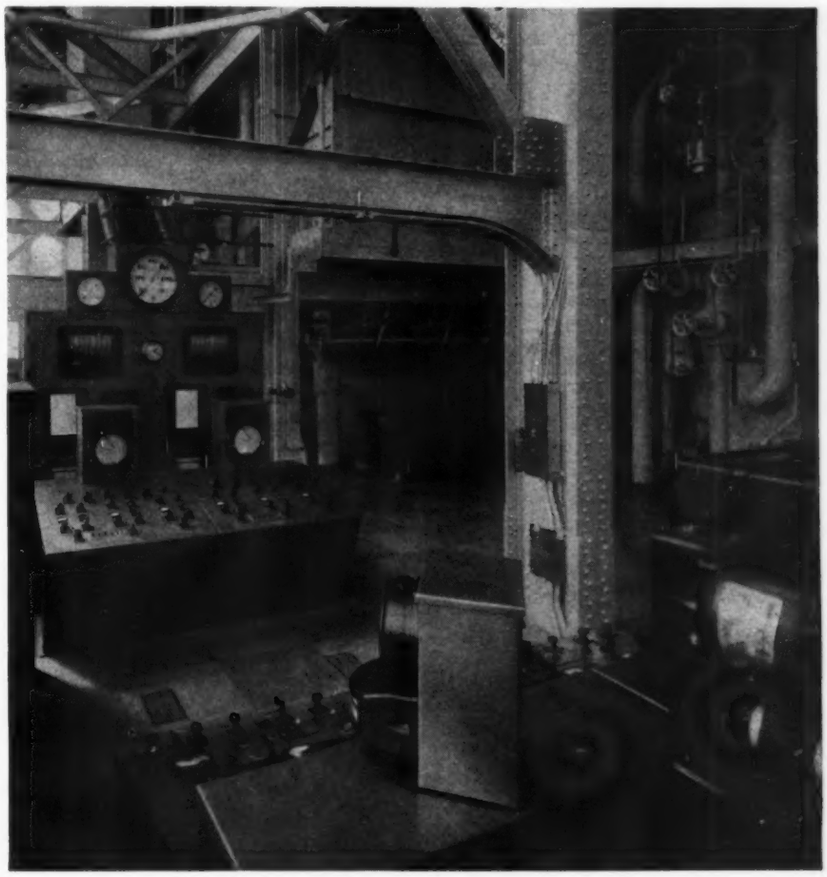


Fig. 8—Boiler control board and switchboard

street lighting, water and sewer systems of modern design.

Performance

Cliffside Unit No. 1 was placed in regular operation on July 9, 1940, Unit No. 2 following on August 11. No severe operating difficulties have been encountered with

Fig. 9—Plant laboratory

any of the equipment during the initial operating period. Experience obtained during this period indicates exceptional responsiveness of controls, convenience and accessibility of layout, and general operating flexibility of the Station as a whole. Performance data available up to the time of preparation of this article indicate that minor adjustments and corrections will enable the Station to readily approximate the expected unit performance listed below:

EXPECTED PERFORMANCE DATA

Steam conditions at throttle: 825 lb gage, 900 F, 4-stage bleeding

Kw output	40,000	40,000	40,000
Back pressure, in. Hg abs	1.0	1.5	2.0
Btu per kwh chargeable to turbine	9,330	9,407	9,534
Overall boiler efficiency, per cent	86.5	86.5	86.5
Used by auxiliaries, per cent	5.0	5.0	5.0
Makeup loss, per cent	1.0	1.0	1.0
Btu per net kw			
100 per cent operating factor	11,469	11,563	11,719
95 per cent operating factor	12,073	12,172	12,336

Completion of the first section of Cliffside gives the Duke Power System a total generating capacity of 1,020,803 kw, made up of hydro- and steam-generating capacities as follows:

Hydro, operated	499,253 kw
Hydro, purchased	99,550 kw
Steam, operated	400,750 kw
Steam, purchased	21,250 kw
Total	1,020,803 kw

In addition to the foregoing, there is under construction at the present time an 80,000-kw addition to the Buck Steam Station, located near Spencer, N. C. This unit is scheduled for operation early in June 1941.

The design and construction of Cliffside Steam Station was handled by the Engineering and Construction Departments of the Duke Power Company's organization in Charlotte, N. C., under the supervision of Charles I. Burkholder, Vice President and Chief Engineer.

Principal Equipment

Cliffside Steam Station—Duke Power Co.

BOILER EQUIPMENT

Boilers

Two, bent-tube, four-drum, 18,200 sq ft each, design pressure 900 lb.—*Combustion Engineering Company, Inc.*

Superheaters

"Elesco" interbank convection type, 9600 sq ft each.—*Combustion Engineering Company, Inc.*

Superheater Control

Motor-operated bypass dampers.—*Combustion Engineering Company, Inc.*

Furnaces

Two, 6061 sq ft heating surface, 19,300 cu ft effective furnace volume. *Combustion Engineering Company, Inc.*

Pulverizing Mills

Three per boiler, Raymond bowl type, 10 tons per hour each, at 50 per cent grindability and 10 per cent moisture, driven by 200-hp, 1200-rpm, 550-volt squirrel-cage constant-speed G.E. motors.—*Combustion Engineering Company, Inc.*

Mill Feeders

One per mill, integral-mill type, driven by a 1-hp, 1200-rpm, 550-volt constant-speed motor, through a Sterling feeder drive, speed range 3 to 12 rpm.—*Combustion Engineering Company, Inc.*

Exhausters

One per mill, open-wheel type, driven from mill shaft at 1200 rpm.—*Combustion Engineering Company, Inc.*

Burners

Four sets per boiler—made up of three 10-in. coal nozzles and two 1-in. oil nozzles (for lighting off) surrounded by seven hot-air admission ports, arranged for corner-tangential firing.—*Combustion Engineering Company, Inc.*

Forced-Draft Fans

One per boiler, 117,000 cfm, 10.8 s.p. at 1145 rpm, each driven by a 300-hp, 1200-rpm, 550-volt, squirrel-cage constant-speed Allis-Chalmers motor, through a 27-in. Class III type, hydraulic coupling.—*American Blower Corporation.*

Induced-Draft Fans

One per boiler, 215,000 cfm, 14.5 s.p. at 682 rpm, each driven by a 700-hp, 720-rpm, 550-volt, squirrel-cage constant-speed Allis-Chalmers motor, through a 42-in. Class III type, hydraulic coupling.—*American Blower Corporation.*

Air Preheaters

One per boiler, Ljungstrom regenerative type, CGZX-No. 20½, heating surface 38,900 sq ft.—*Air Preheater Corporation.*

Stacks

One per boiler, 10 ft 6 in. × 70 ft, unlined steel.—*Carolina Steel & Iron Company.*

Breechings and Ducts

Carolina Steel & Iron Company.

Pressure-Reducing Valves

Fisher Governor Company.

Feedwater Regulators

One 6-in. three-element control per boiler; air operated.—*Bailey Meter Company.*

Soot Blowers

Twenty per boiler, 14 revolving type, 6 retractable type.—*Diamond Power Specialty Company.*

Water Columns

Two per boiler, with high- and low-water alarms. One column fitted with bi-colored gage and illuminated, with mirrors to main firing board.—*Diamond Power Specialty Company.*

Safety Valves

Four per boiler.—*Consolidated Ashcroft Hancock Company.*

Blowoff Valves

Two per boiler, 2-in. Yarway unit tandem type.—*Yarnall-Waring Company*

Blowoff Tank

Chattanooga Boiler & Tank Company.

COAL AND ASH-HANDLING EQUIPMENT

Unloading and Conveying System

Shaking feeders, belt conveyors and flight conveyor, 300 tons per hour capacity.—*Robins Conveying Belt Company.*

Coal Crusher

One 7-ft × 11-ft Bradford Hammermill.—*Pennsylvania Crusher Company.*

Coal Storage

One 8-yd Crescent coal scraper with mobile tail-car all controlled from a central tower.—*Sauerman Bros., Inc.*

Track Scales

Two, four-section railway track scales of 75-tons-per-section capacity, 50-ft platform with dead rail.—*Winslow Gov't. Standard Scales Wks.*

Raw Coal Bunkers

Two rectangular type—capacity 400 tons each.—*Virginia Bridge Company.*

Coal Weightometer
One 36-in. wide.—*Merrick Scales Mfg. Company.*

TURBINE EQUIPMENT

Turbine-generator Units
Two 20-stage tandem-compound, 40,000-kw, 50,000-kva, 13,200-volt, 3600-rpm, designed for 825-lb gage, 900 F steam and 4-stage bleeding; with hydrogen-cooled generator and a 185-kw, 250-volt exciter, and 4-kw pilot exciter, driven off generator shaft through a reduction gear.—*General Electric Company.*

Hydrogen Coolers
Four sections per unit located in stator frame connected to raw water. Total surface 5400 sq ft per unit.—*General Electric Company.*

Turbine Oil Coolers
Two per unit.—*Andale Company.*

Condensers
Two 33,000 sq ft horizontal, divided water-box type, two-pass, with 5260 1-in. × 24-ft 3-in. admiralty metal tubes, welded steel shell, cast-iron water boxes.—*C. H. Wheeler Manufacturing Co.*

Circulating Water Pumps
Two per unit, single-stage centrifugal, 18,500 gpm at 28 ft 3 in. head each, driven by a 200-hp, 360-rpm, 550-volt G.E. squirrel-cage motor.—*C. H. Wheeler Manufacturing Co.*

Condensate Pumps
Two (duplicate) two-stage centrifugal per unit, each good for 700 gpm, at 186-ft head, driven by 60-hp, 1200-rpm, 550-volt, G.E. squirrel-cage motors —*C. H. Wheeler Manufacturing Co.*

Air Pumps
Two (duplicate) tube-jet type per unit, two-stage with combined inter- and after-condenser.—*C. H. Wheeler Manufacturing Co.*

Expansion Joints
Condenser circulating water lines—four per unit—30-in. rubber.—*Moisson Packing and Ribber Company.*
Low-pressure extraction lines—two per unit—14-in. copper, and
Boiler-feed pump suction lines—four—8-in. copper.—*Joseph Kopperman & Sons.*

FEEDWATER HEATING EQUIPMENT

Stage Heaters
Three per unit, vertical condenser type, lockhead design. High-pressure heaters Nos. 1 & 2 are two-pass; low-pressure heater, No. 4 is four-pass. Heater No. 1 (h.p.) has 398 3/4-in. × 21-ft, 12-ga. tubes; heater No. 2 (i.p.) has 382 3/4-in. × 19-ft, 15-ga. tubes; heater No. 4 (l.p.) has 408 3/4-in. × 17-ft 9-in., 18-ga. tubes. Tube material: arsenical copper.—*Foster Wheeler Corporation.*

Vapor Condenser
One, with twenty-eight 1-in. × 11-ft, 18-ga. admiralty metal tubes.—*Foster Wheeler Corporation.*

Deaerators
One per unit, vertical cylindrical direct-contact type, 9-ft welded steel shell, 144 6-in. × 36-in. heating and 480 6-in. × 36-in. cast-iron deaerating trays. Equipped with 400 sq ft vent condenser.—*Cochrane Corporation.*

Boiler Feed Pumps
Four 6-in. six-stage, type 6UXS-2 centrifugal pumps with bypass connections. Each delivers 850 gpm. of 257 F water against 2475-ft head, at 3570 rpm. One pump connected to 700-hp single-stage Moore turbine. Three pumps direct-connected to 700-hp, 550-volt Allis-Chalmers motors.—*Worthington Pump and Machine Company.*

Surge Tanks
Three, two upper, capacity 15,000 gal each; one lower, capacity 25,000 gal.—*Carolina Steel & Iron Company.*

Low Surge Tank Pumps
Two single-stage 400-gpm, 150 ft-head, direct-connected to 25-hp, 1800-rpm. 550-volt G.E. induction motor.—*Worthington Pump and Machine Company.*

Evaporator
One per unit, type "H," submerged-coil single-effect; 42 1-in. O.D. arsenical copper coils, 246 sq ft; capacity 8000 lb per h.—*Foster Wheeler Corporation.*

Evaporator Feed Heater
One per unit, 2 ft 4 1/2 in. sq. × 5 ft 6 in. high, cast iron, designed for 5 lb water pressure; capacity of 8000 lb per hr.—*Cochrane Corporation.*

High-Pressure Drainage Control
One per unit.—*Northern Equipment Company.*
High-pressure drainage control tank—one per unit.—*Henry Vogt Machine Co.*

AUXILIARY PUMPS

High-Pressure Service Pumps
Two, two-stage, 1350 gpm at 310-ft head, driven by 150-hp, 1800-rpm, 550-volt G.E. squirrel-cage motor.—*Worthington Pump and Machine Company.*

Low-Pressure Service Pumps
Two, single-stage, 1800-gpm at 100-ft. head, driven by 60-hp, 1800-rpm, 550-volt G.E. squirrel-cage motors.—*Worthington Pump and Machine Company.*

Sump Pumps
Two, single-stage 3-in., 250-gpm at 45 ft head, direct-connected to 5-hp, 1800-rpm, 550-volt Westinghouse induction motors.—*Goulds Pumps, Inc.*

Tunnel Pump
One, 12-in. single-stage double-suction, 3000-gpm at 50-ft head, direct-connected to a 50-hp, 1200-rpm, 550-volt G.E. induction motor.—*DeLaval Steam Turbine Co.*

Twin Strainers
Elliott Company.

INSTRUMENTS AND GAGES

Steam Flowmeters
One per unit, synchro-meter for turbine throttle flow.—*Bailey Meter Co.*

Boiler Meters
One per boiler.—*Bailey Meter Co.*

Draft Gages
One per boiler, multipointer.—*Bailey Meter Co.*

Feedwater Flowmeters
One per boiler.—*Bailey Meter Co.*

Boiler Water-Level Recorder
One per boiler.—*Bailey Meter Co.*

Temperature Recorders
Air preheaters—two; Pulverizer Mill discharge—two.—*Bailey Meter Co.*
Feedwater—two.—*Brown Instrument Co.*

Conductivity Recorders
One per unit.—*Leeds and Northrup Company.*

Pressure Gages
Consolidated Ashcraft Hancock Co.

Recording Pressure Gages
Brown Instrument Co.

Condensate Flowmeter
One per unit, Venturi type.—*Builders Iron Foundry.*

Annunciator System
Two—between boiler control board and lighting-off panel.—*Edwards & Company.*

Turbine Supervisory & Hydrogen Control
General Electric Company.

AUXILIARY EQUIPMENT

Traveling Screens
Two, 31-ft 6-in. centers × 10 ft wide.—*Link-Belt Company.*

Turbine Room Crane
One, with 100-ton main and 15-ton auxiliary hoists, 90-ft span.—*Cleveland Crane & Engineering Co.*

Machine Shop Crane
One, 5-ton, 23-ft 9 7/8-in. span.—*Shepard Niles Crane & Hoist Corp.*

Intake-Structure Crane
One, 15-ton, 18-ft span.—*Shepard Niles Crane & Hoist Corp.*

Ash Hoist
One 3/4-cu-yd, 2 1/2-ton monorail grab-bucket electric hoist.—*Shepard Niles Crane and Hoist Corp.*

Air Compressors
Two, type ESI, 331-cfm, 100-lb pressure with Texrope drive and 75-hp, 1200-rpm, 550-volt G.E. induction motors.—*Ingersoll-Rand Company.*

Turbine Oil Purifiers
Two No. 65-15 "Uni-matic"—*De Laval Separator Co.*

Elevated Water-Storage Tank
50,000 gal on an 84-ft tower; 10,000 gal auxiliary filtered water tank.—*R. D. Cole Mfg. Co.*

Piping
Grinnell Company.

Pipe and Duct Insulation
W. Reid Hayden, Inc.

Valves
Gates, checks and high-pressure globes.—*Chapman Valve Mfg. Co.*

Valves
Non-return and forged steel.—*Edward Valve & Mfg. Co.*

Control Boards and Instrument Panels
General Electric Company

Motor-Generators
One, 25-kw, 1800-rpm, 250-volt direct-connected to a 40-hp, 550-volt motor.—*General Electric Company.*

Battery Charges
One Phano-Charger, 250–280 volts, 12.5 amp for 550-volt source.—*General Electric Company.*

Storage Batteries
120 cells.—*The Electric Storage Battery Co.*

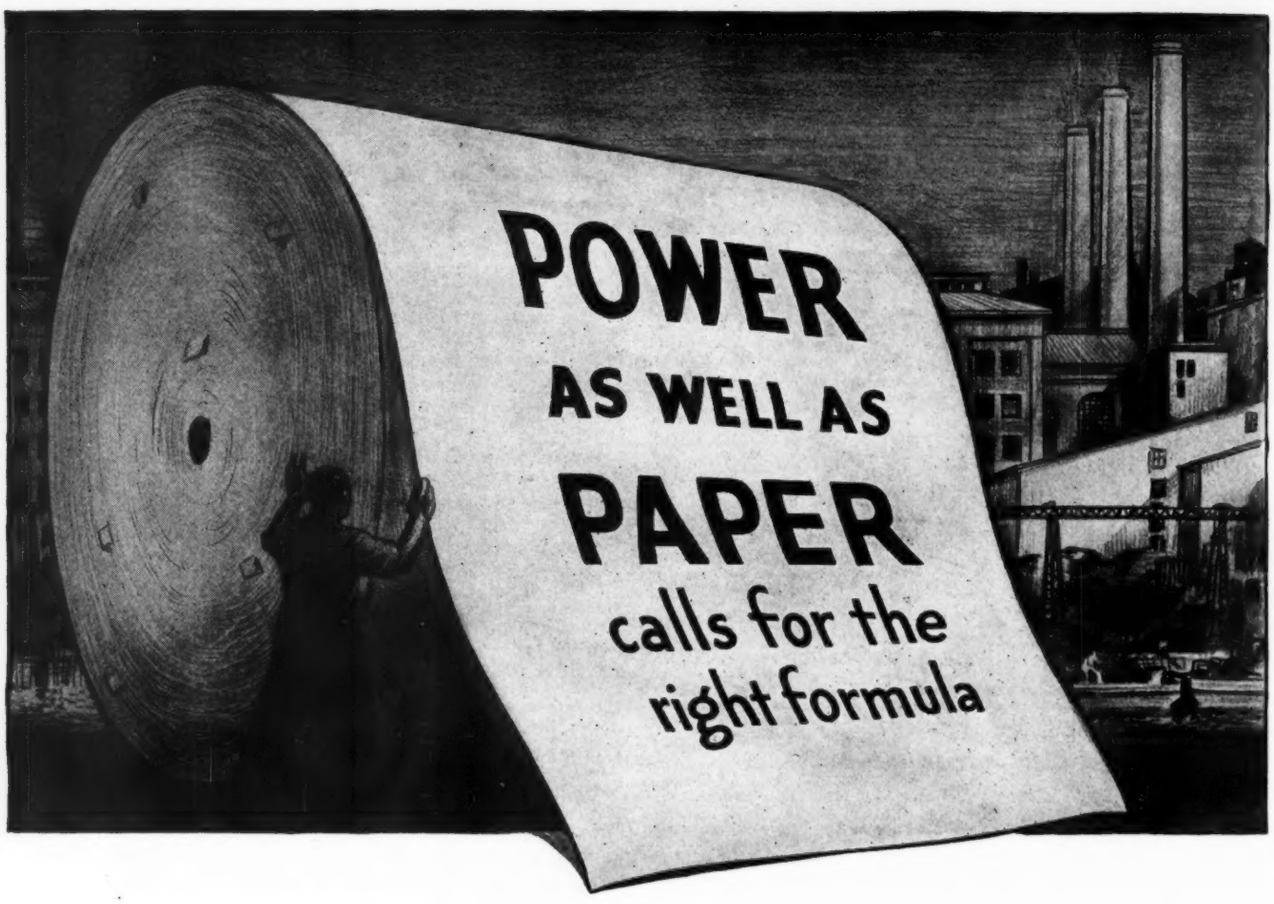
SUBSTATION EQUIPMENT

Transformers
Main, four 3-ph 25,000-kva, 13,200 to 44,000 and 88,000 volts.—*General Electric Co.*
Auxiliary, six, single-phase 1250-kva, 13,200 to 550 volts, one 3-ph 1500 kva, 44,000 to 550 volts.—*Allis-Chalmers Mfg. Co.*

Oil Circuit-Breakers
Eight 88,000 volts, 600 amp. Two 46,000 volts, 1200 amp. Two 15,000 volts, 3000 amp.—*Westinghouse Elec. & Mfg. Co.*

Mulsifier System
Grinnell Company.

[The Editor wishes to acknowledge the cooperation of *Southern Power and Industry*, particularly, in making available certain of the line drawings prepared for a similar article by Mr. Williams, which appears in its current issue]



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GENERAL COAL

Economy in Boiler-Water Recirculation

By M. D. BAKER

Chief Chemist, West Penn Power Company

In the method employed at Springdale Station, the boiler-drum water is recirculated to the feedwater cycle at the economizer inlet, hence requires only sufficient pumping power to overcome the pressure drop through the economizer. Among its other advantages are conservation of heat in the boiler water, maintained efficiency of oxygen-absorbing chemicals, elimination of metering errors and avoidance of the necessity of regulating blowdown. Appended tables give the results obtained with this method under high-pressure operation at Springdale.

ECONOMIZER and boiler-metal protection obtained by the recirculation of water from the boiler drum of the feedwater cycle is in use in many power stations throughout the country. Recirculation is of particular benefit in stations using distilled water or water of low hardness, as the maintenance of a protective pH value and the presence of oxygen-absorbing chemicals in the water are essential to protect the economizer from corrosion. Another method for obtaining this protection is the constant addition of caustic and oxygen-absorbing chemicals. This procedure results in excessive concentrations of alkalinity and oxygen-absorbing chemicals in the boiler water, the reduction of which requires increased blowdown, which in turn necessitates increased make-up.

S. M. Sperry[1] describes a method for obtaining this protection in which a portion of the boiler blowdown is returned to the deaerating heater. The volume of the return is regulated to raise the pH of the feedwater from 6.6 to 8.6 and is estimated to be one per cent of the evaporation of the boilers. The amount of water recirculated requires approximately 40 hp of pump capacity to protect a 55,000-kw station.

Maguire and Tomlinson[2] describe a method in which the boiler water is returned to the hot-process softener. This method applies to the recovery of chemicals in the softener, but does not offer any additional economizer protection over that of the usual softened water. However, because of pumping through the filter, the power required to pump the water back to boiler-feed pressure by the second method would be more than that needed in the method used by Mr. Sperry.

[1] "The Recirculation of Boiler Salines," by S. M. Sperry, COMBUSTION, June, 1939.

[2] "The Recirculation of Boiler Water to Hot-Process Softener," by John J. Maguire and W. J. Tomlinson, COMBUSTION, September, 1939.

In each of the above methods, the heat in the boiler water is degraded to that of the deaerating heater or lower, which materially affects the economy. Also, oxygen-absorbing chemicals are rendered ineffective due to being saturated by the large amounts of oxygen present in the water entering the deaerator or softener. The power required by each of these methods is considerable, and to recirculate more than the minimum amount needed for protection unnecessarily increases the cost. Consequently, any attempt to conserve power introduces the hazard of under-treatment.

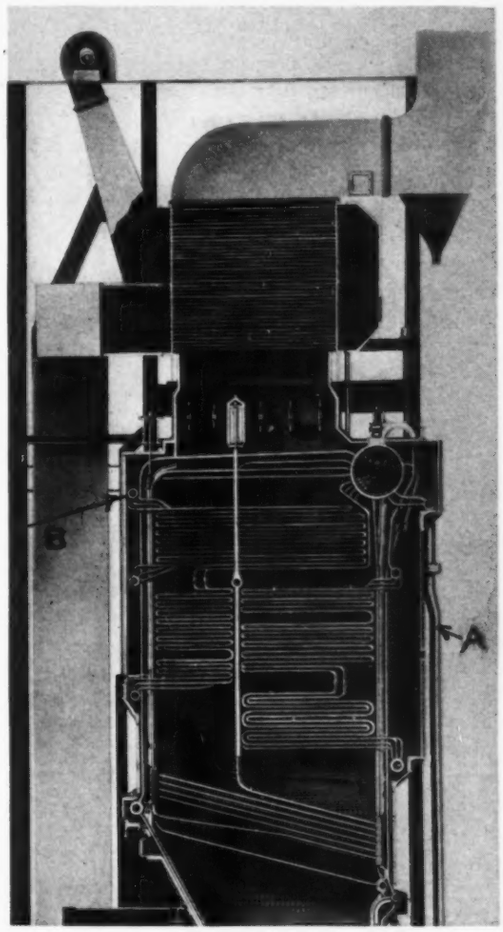

Fig. 1—Cross-section through boiler showing points at which recirculated water is taken and admitted

A third method of recirculation, in successful use at Springdale Station for three years, is the recirculation of boiler-drum water to the feedwater cycle at the econo-

mizer inlet. This method has the following advantages over the methods outlined above:

1. Requires only the power needed to overcome economizer friction.
2. Conserves the value of the heat in the boiler water.
3. Maintains the efficacy of the oxygen-absorbing chemicals.
4. Removes possibility of metering errors.
5. Insures continuous protection of the economizer.
6. Eliminates steam binding in the economizer.
7. Provides pressure for chemically conditioning the water of individual boilers.
8. Relieves the operators from the necessity of regulating blowdown to condition feedwater.

Many of these advantages were recognized by the engineers who designed the topping addition to the Springdale Station of the West Penn Power Company, and means for obtaining these advantages were given full and careful consideration.

A brief description of the 1938 addition at Springdale will help in appreciating the duty imposed upon the recirculating unit. The topping station comprises a 50,000-kw turbine-generator and three 450,000-lb per hr high-head cross-drum boilers generating steam at 1300 lb per sq in. pressure and 935 F total temperature. The temperature of the boiler water at this pressure is 577 F. The economizers and superheaters are built integrally with the boilers, and dampers in the gas passages are used to control the temperature of the superheated steam. Integral design makes it imperative that the greatest possible protection against corrosion of the heating surfaces be provided.

Thorough inquiries for a pump designed to handle the high-pressure, high-temperature, alkaline boiler water disclosed that such a pump had not then been produced, and all efforts to induce the manufacturers to develop a pump for this service met with complete failure. Packing the pump against the high pressure, in conjunction with the solvent properties of the hot alkaline boiler water, seemed to offer unsurmountable difficulties. In addition, the heat generated by the high-speed shaft in the hydraulically loaded packing added to the problem.

West Penn Power Company engineers then developed to their own specifications a single-stage centrifugal pump for the purpose. It has special internal insulation to retard the flow of heat from the hot liquid to the section of the pump containing the shaft packing. A conventional water-cooled stuffing box is provided to remove such heat as flows across this retarding insulation. The frictional heat generated by the rotating shaft is removed by making this driving shaft hollow to allow internal cooling. The resulting design gives a dual-temperature pump. The hot volute section contains the runner and the inlet and discharge ports, and the cooler section the packing.

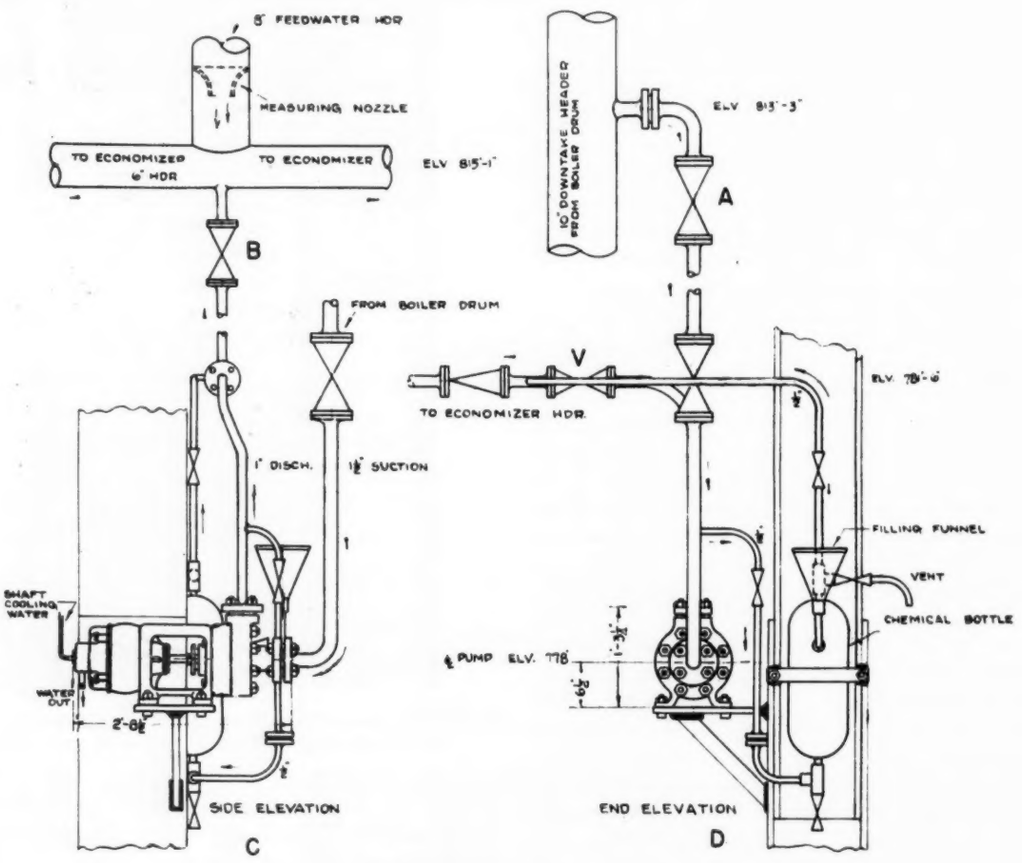

Fig. 2—Sketch of recirculator and connections

This recirculating unit is a compact design with the central frame casting carrying the pump on one end, and the driving motor on the other. The motor is a 3-hp three-phase induction type, running at 3500 rpm, and should give long and dependable service as the load imposed to recirculate 40 gpm requires only 2 hp.

Results obtained with the first recirculator fully justified the efforts and hopes of the engineers, as this unit gave $4^1/_2$ months of satisfactory service before there was evidence of failure. An inspection at this time showed that the internal heat insulation had deteriorated. Some trouble was experienced in finding an insulation that would withstand the severe service. This insulation problem was finally solved by using a metallic rather than a ceramic material. Metallic insulating units with two years' continuous service show no deterioration.

Strange as it may seem, the greatest difficulty encountered was with the ball bearings carrying the hydraulic thrust. The service imposed on these bearings is much more severe than that ordinarily encountered, as the hydraulic load is continuous as long as the boiler is under pressure. The rotation is always in one direction and there is no outage for recoating of the surfaces. This bearing difficulty was overcome by multiplying the capacity of the thrust bearing and improving the lubrication. Proper lubrication is essential for satisfactory bearing performance.

Improved recirculators now in operation are in their tenth month of continuous service and show no evidence of failure or distress. So far as can be determined, it is believed that these units, as now designed and in use, will give service comparable to that of other dependable equipment in the modern power station.

Recirculation Connections

Fig. 1 is a cross-sectional view, showing part of one of the new high-pressure boilers. Water for recirculation is obtained from the downtake header at point *A* and, after passing through the recirculator, it is admitted into the feedwater line beyond the water-level control valve and metering nozzle, where it separates to supply both ends of the economizer inlet header, indicated at *B*.

Fig. 2 is a sketch showing the points where the recirculator is connected. In this, *A* is the connection on the downtake header that supplies the recirculator, *B* is the point for readmitting the boiler water into the feedwater line, *C* is a side elevation of the recirculator, and *D* is an end elevation of the unit with the chemical bottle that is used, when needed, to feed conditioning chemicals to the individual boiler. The installation of the bottle on the pump discharge eliminates the necessity of passing strong chemical solutions through the pump. The rate of admission of the chemicals to the boiler water is controlled by the pressure drop created by operating valve *V* to force the chemical solution out of the bottle.

Fig. 3 is a photograph of a recirculator in service.

All boiler feedwater is treated continuously with a minimum amount of disodium phosphate and caustic to take care of condenser leakage. Sodium sulphite is added to absorb occasional traces of oxygen. The normal daily treatment is six pounds of disodium phosphate, three pounds of caustic and six pounds of sodium sulphite for an evaporation of 30,000,000 lb. The normal feedwater has a total concentration of about 1 ppm with a pH value of 7.5 to 8.5, which fluctuates with the amount of dissolved ammonia in the water. The excess of sodium sulphite in the boiler water varies between 2 and 10 ppm. No trouble is experienced with decomposition of the sulphite, and a reasonable balance can always be made between the sulphite added, the oxygen entering the system and the resulting sulphate in the boiler water.

Oxygen enters the feedwater system at irregular intervals, as at times of putting on or taking a turbine out of service. The excess of sodium sulphite in the boiler water insures constant economizer protection from oxygen, as recirculation provides the presence of sulphite at the economizer inlet. Recirculation also gives a pH value of 8.9 or higher in the economizer. Because of the unbuffered nature of the feedwater, a small amount of boiler water produces a large increase in pH value. This reduces the amount of caustic treatment that would otherwise be required.

Makeup water to replace blowdown may be more important in a condensate station than in a 100 per cent

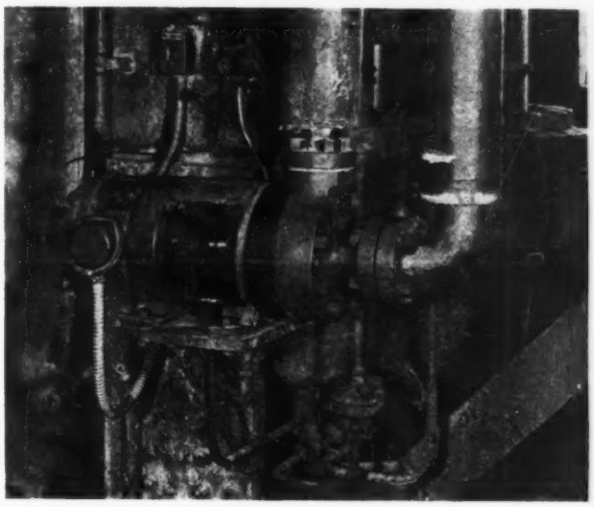

Fig. 3—A recirculator in service

makeup station, as water blown down has to be replaced by evaporation. The lower the concentration of the feedwater, the less the amount that has to be blown down or wasted. Also, the higher the boiler water concentration that is carried, the smaller the blowdown loss. One ppm in the feedwater, which is now used at Springdale, requires less blowdown than 3 ppm, the minimum concentration which could be expected to protect the boiler without recirculation. Recirculation now insures full protection at all times, as the low average of the water entering the economizer is 20 ppm. Table 1 gives the blowdown in pounds and in per cent of evaporation for 1, 3 and 20 ppm feedwater, and with 500 and 2000 ppm boiler-water concentrations.

TABLE 1

Feedwater Concentration, Ppm	Boiler-Water Concentration, Ppm	Blowdown in % of Evaporation	Blowdown, Pounds per Day for 3 Boilers
1	500	0.2	21,600
	2000	0.05	5,400
3	500	0.6	64,800
	2000	0.15	16,200
20	500	4.0	432,000
	2000	1.0	108,000

Table 2 gives the history of a Springdale boiler at various concentrations and itemizes the concentration

and pH value of the boiler water recirculated, the pH value of the feedwater before addition of the boiler water, and after the addition of the boiler water, and indicates the benefits obtained when carrying the various concentrations.

TABLE 2

Boiler Water		Feedwater pH Value		
			After Recirculation	
Concentration, Ppm	pH Value	Before Recirculation	North Economizer Inlet	South Economizer Inlet
102	10.0	8.3	8.8	8.5
189	10.6	7.4	8.6	8.9
292	10.8	8.0	9.1	9.0
407	10.9	7.9	9.1	9.1
511	10.8	7.5	9.2	9.0
607	10.9	8.2	9.8	9.5
709	11.1	7.8	9.6	9.2
817	11.1	8.5	8.9	9.0
898	11.3	8.8	9.8	9.3
1022	11.2	8.8	9.6	9.5
1570	11.1	8.4	9.8	9.6
2060	11.0	7.4	9.5	9.2

pH value determined by glass electrode. No sodium correction made.

Table 3 gives typical results obtained simultaneously from the three boilers.

TABLE 3

Boiler No.	2	4	6
Total solids, ppm	1692	1896	1728
Total alkalinity eqv.	4.5	5.0	4.3
Hydroxide eqv.	3.3	3.7	3.9
Sulphite, ppm	2	2	1
pH value (glass electrode)	11.0	11.0	11.0
Feedwater, pH original	7.5	7.5	7.5
Feedwater, total solids orig., ppm	1.4	1.4	1.4
Feedwater, north econ. inlet pH	9.2	9.7	9.4
Feedwater, north econ. inlet total solids, ppm	25	59	37
Feedwater, south econ. inlet not determined	..	..	..

Conclusions

Recirculation of boiler water from the drum to the economizer inlet requires only sufficient power to overcome the pressure drop through the economizer, or 2 hp for each of the three boilers at Springdale. The steam produced by these boilers generates 150,000 kw. Other methods require that the water be pumped from either the deaerator or the softener to the full feedwater pressure.

A heat unit at the temperature of the water in the boiler is much more valuable than it is at the temperature of the water earlier in the feedwater cycle. Any method of recirculation that prevents the degradation of heat is a method for better efficiency. Removing water from the boiler drum and returning it to the economizer is accomplished with slight change in the value of the heat units.

Deaeration of boiler feedwater is cheapest when obtained by thermal methods. The traces of oxygen not removed by this means can be removed chemically. Oxygen at the economizer inlet will cause material damage; therefore, sodium sulphite introduced at this point produces the greatest protection. Recirculation of sodium sulphite to the economizer inlet does not waste it in removing oxygen that should be removed by thermal means.

Boiler water recirculated to the feedwater after the point of metering does not affect any record or calculation; hence, in no way is there interference with accurate records or information.

Boiler feedwater containing twenty or more parts of conditioned boiler water has a high pH value and an excess of sodium sulphite, and as a result gives full protection to the economizer.

One of the difficulties now encountered in placing some boilers in service and during varying load periods is steam binding in the economizer. The recirculation of a constant amount of drum water through the economizer washes the steam that is generated into the drum. This recirculation helps to stabilize the water level in the drum.

Irregularities in operation affect boiler-water conditions so that boilers require individual treatment. This is easily accomplished by placing a chemical bottle at the discharge side of the pump and forcing the required chemical into the boiler water at any rate desired. Chemicals added in this manner are diluted and do not have as great a tendency to cause foaming as when they are admitted directly into the boiler drum.

Regulation of blowdown to adjust the pH value in the feedwater or to maintain satisfactory softener conditions requires periodic analyses of the water. When the boiler water is recirculated direct to the economizer inlet, ample water to give full protection is received and requires no regulation or water analyses. Blowdown to maintain water conditions are thus made independent of feedwater conditions.

Recirculation by any method minimizes chemical costs, saves blowdowns, reduces makeup requirements and provides metal protection. The method employed at Springdale, in addition to the above, uses less power, conserves heat values, eliminates steam binding in the economizer and provides a means for the easy addition of conditioning chemicals.

Smooth Flow to Oil Burners

The De Laval-IMO delivers oil without shock or pulsation as would a piston moving always in one direction. The uniform delivery and pressure are necessary for good combustion.

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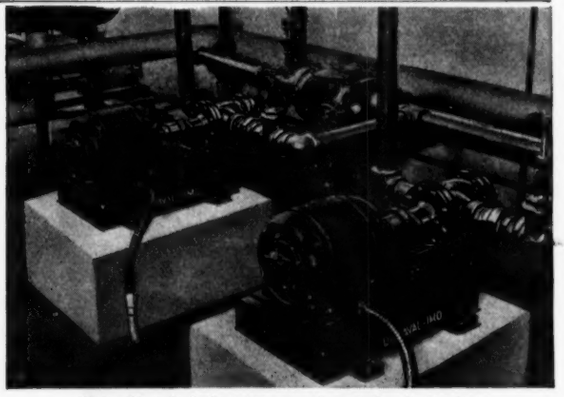

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ENTHALPY AND ENTROPY

An elementary discussion of the relationship of heat and work, the conservation of energy, entropy, cycle processes and reversibility as basis for their application to the generation of power.

The First and Second Laws of Thermodynamics

By Dr. ERICH F. LEIB

Combustion Engineering Company, Inc.

ENERGY which drives engines in power plants is generated through conversion of heat. In order to understand the possibilities and limitations of such a conversion, it is necessary to know the amount of work which can be made available in a given thermal process. The relationship between heat and work is expressed by two fundamental principles which are known as the First and Second Laws of Thermodynamics. The following introduction intends to facilitate the study of the problems involved.

Equivalence of Heat and Work

Consider a cylinder containing one lb of gas. At a given temperature T and a given pressure p acting on the piston, the gas has the volume v. First, we add heat from the outside so that the temperature of the gas is raised one deg F, while the piston is held in its initial position by raising the outside pressure slightly. The amount of heat supplied is called the specific heat at constant volume c_v. Then, we consider the same initial condition (pressure, temperature, volume) of the gas as before, but we keep the pressure on the piston constant. While we add again the necessary heat to raise the temperature one deg F, the piston gives way to the slightly expanding gas which thus assumes the volume $v + dv$. The amount of heat supplied is called the specific heat at constant pressure c_p.

Comparing the heat quantities in both cases, we find c_p greater than c_v. Trying to explain this, we notice that, heated under constant pressure, the expanding gas moved the piston against the outside pressure, thus performing a certain amount of mechanical work, while no such work was performed by the gas heated under constant volume. The work of expansion is obtained from the well-known definition

$$\text{Work} = \text{force} \times \text{distance}$$

If the piston is displaced by the infinitesimal distance dl against the force F, the infinitesimal amount of work performed is

$$dW = F \times dl \tag{1}$$

If the area of the piston is A, we obtain the pressure on the piston as

$$p = \frac{F}{A} \tag{2}$$

The increase in the cylindrical gas space due to the displacement of the piston is

$$dv = A\, dl \tag{3}$$

By substitution of equations (2) and (3) into (1), the work of expansion is obtained as

$$dW = p\, dv \tag{4}$$

We are now in a position to measure the mechanical work due to the expansion dv against the pressure p. If the unit of volume is ft³ and the unit of pressure is taken as lb/ft², then the unit of work is ft-lb.

If the above experiment is carried out for various gases and at different temperatures, it is observed that, for the same amount of work, also the excess of c_p over c_v corresponds to the same amount of heat. Thus, it can be concluded that this excess heat is expended on the production of the work done by the gas, and we obtain for gases the relation

$$c_p - c_v = R \tag{5}$$

where R depends only on the molecular weight of the gas and therefore is called the gas constant. The excess heat R can be measured in heat units, Btu. Furthermore, R represents the work of expansion done by one lb of gas against the pressure p, due to a temperature rise of one deg F, measured in ft-lb. By comparison of the values obtained in both units, we find that

$$1 \text{ Btu} = 778.26 \text{ ft-lb} \tag{6}$$

The equivalence of heat and work, as expressed by equation (6), has been proved true wherever heat is converted into work and vice versa, and therefore has been adopted as a fundamental principle of physics.

Conservation of Energy

It follows from the principle derived, that thermal energy cannot be increased and work cannot be produced without supplying an equivalent amount of heat. Then, if the amount of heat dQ' is supplied to a substance, it serves either to increase the internal energy u or to produce work. This yields the relation

$$dQ' = du + dW \tag{7}$$

From the work of expansion W, we can derive the work made available in engines. If the working substance has the initial volume v_1 and pressure p_1, the work p_1v_1 necessary to move the piston until the substance fills the volume v_1 is done by the reservoir from which the substance is taken and represents a gain in work. If the substance expands in the engine to the final volume v_2 and pressure p_2, the work p_2v_2, necessary to discharge the substance against the back pressure, has to be done by the engine and represents a loss in work. Thus, the available external work is

$$L = W + p_1v_1 - p_2v_2$$

and for an infinitely small expansion

$$dL = dW - d(pv) \tag{8}$$

If the value of dW is substituted from (4), we obtain

$$dL = p\,dv - d(pv) = -v\,dp \tag{9}$$

Substitution of (8) into (7) gives

$$dQ' = du + d(pv) + dL \tag{10}$$

If we introduce the quantity

$$h = u + pv \tag{11}$$

we can write for (10)

$$dQ' = dh + dL \tag{12}$$

or, from (9),

$$dQ' = dh - v\,dp \tag{13}$$

The quantity h is the total heat of the substance, named "Enthalpy" by Kamerlingh Onnes, i.e., "inherent heat."

If the pressure is kept constant, the second term in (13) cancels; thus, the increase in enthalpy corresponds to the heat supplied at constant pressure. This applies to the generation of steam in boilers and many other processes of heat transfer, where no external work is done.

If the substance under consideration is in motion, it possesses also kinetic energy, K. Since this kind of energy is also convertible into work, it has to be included in the energy balance (12):

$$dQ' = dh + dK + dL \tag{14}$$

The kinetic energy has the particular property that it can, partially or entirely, be converted into heat by friction, thereby creating heat within the substance. This heat dQ'' must be added to the outside heat dQ' in the energy balance (14), and the total amount of heat supplied is

$$dQ = dQ' + dQ'' \tag{15}$$

Since dQ'' represents heat created, it is always positive. Then, equation (14) gives

$$dQ = dh + dK + dL \tag{16}$$

which states that the total amount of all kinds of energy, including any kind of heat, remains constant and that only transformations from one sort into another are possible.

This statement is the *Law of Conservation of Energy*. If energy could be created without consuming any other kind of energy, we would have a case of "perpetual motion." The Law of Conservation of Energy states that perpetual motion is impossible.

The First Law of Thermodynamics

Equation (16) can be written

$$dh = dQ - (dK + dL) \tag{17}$$

which states that, if no equivalent amount of heat is supplied, the substance is not able to produce work or kinetic energy without a permanent decrease in enthalpy. This principle is the *First Law of Thermodynamics*. Enthalpy has a definite value for each state of the substance, and therefore is referred to as a "property of state." Consequently, in a change of state from an initial state 1 to a final state 2, the enthalpy changes by a definite amount dh. On the other hand, the heat supplied, the work done and the change in kinetic energy may assume arbitrary values, depending on the path by which state 2 is reached from state 1, since Q, K and L are not properties of state. Only the sum $dQ - (dK + dL)$ is determined by the change of state.

If, during any moment of a change of state, no heat is supplied, neither from outside nor inside the substance, we have in (17)

$$dQ = 0 \tag{18}$$

and

$$-dh = dK + dL \tag{19}$$

Such a process is referred to as "adiabatic," i.e., "impermeable to heat."

In this case, the external work or kinetic energy is produced solely at the expense of the enthalpy. This applies to the change of state in such engines where no heat is exchanged with the outside and friction can be neglected. In cylinder engines, the change in kinetic energy can also be neglected ($dK = 0$) which gives

$$dL = -dh \tag{20}$$

Thus, the work done in an adiabatic process equals the decrease in enthalpy.

In turbines also no heat is supplied from outside ($dQ' = 0$), and no external work is done ($dL = 0$). Instead, enthalpy is transformed into kinetic energy. This transformation is accompanied by a certain loss, since part of the kinetic energy is consumed by friction and immediately converted into heat, dQ'', which accounts for the deviation from the adiabatic change of state. Thus, equation (16) gives

$$dK = -dh + dQ''$$

Since, in turbines, the change in kinetic energy represents the work done, we can write dL instead of dK and obtain

$$dL = -dh + dQ''$$

Thus, in a non-adiabatic change of state, the total work equals the decrease in enthalpy plus the heat of friction. However, the portion corresponding to the term dQ'' is not available as mechanical work but is expended on the work of friction, and the mechanical work equals again the change in enthalpy which, between given limits of temperature or pressure, is for a non-adiabatic expansion less than for an adiabatic expansion. Consequently, the maximum available work between two given temperatures or pressures without heat supply from outside

is obtained when the change of state is adiabatic. This is possible only when the process traverses a sequence of equilibrium states: if at any moment the pressure and temperature are equal for any part of the substance.

In the throttling process, likewise no heat exchange with outside takes place ($dQ' = 0$) and no external work is done ($dL = 0$). The energy transformations are then again obtained from equation (16). In the orifice, enthalpy is transformed into kinetic energy:

$$-dh = dK$$

In the expansion chamber, this kinetic energy is destroyed by friction, thus representing an equal amount of heat supplied to the substance from within:

$$-dK = dQ''$$

which is immediately absorbed and increases the enthalpy:

$$dQ'' = dh$$

Consequently, the enthalpy increases in the expansion chamber by the same amount by which it decreased in the orifice. Thus the enthalpy has the same value before and after the throttling, while during the throttling the substance traverses states with smaller enthalpy values.

Entropy

From a given initial state, only a certain group of states can be reached by an adiabatic process ($dQ = 0$), while all other states cannot be reached by an adiabatic process alone (Principle of Inaccessibility). Therefore, those states which are connected by an adiabatic process must have some property in common which discriminates them from all other states, i.e., there must exist a property of state which assumes the same value for all states which are connected by an adiabatic change of state. Due to the existence of such a quantity, the expression on the right-hand side of equation (16) can be transformed into the differential of this new property of state, s, through division by a suitably chosen function. This function is the absolute temperature, T.

Then we obtain from (16)

$$ds = \frac{dh + dK + dL}{T} \tag{21}$$

Thus, a definite change of the quantity s accompanies each change of state. The quantity s was named "Entropy" by Clausius, i.e., "intrinsic transformation." By comparison of equations (16) and (21), we find

$$dQ = T\,ds \tag{22}$$

Thus, if dQ is divided by the absolute temperature T, the quantity obtained, dQ/T, is also the differential of this new property of state.

It follows from (22) that, if $dQ = 0$, also $ds = 0$. Consequently, the entropy remains constant in an adiabatic change of state. If no heat is supplied from outside, but heat is created within the substance due to friction ($dQ = dQ''$), the entropy increases. For a change of state in which no change in kinetic energy is involved ($dK = 0$), equation (21) yields in conjunction with (9)

$$ds = \frac{dh - v\,dp}{T} \tag{23}$$

From this equation, the value of entropy can be calculated for each state of the substance, since the properties v and h as functions of p and T are known.

The Second Law of Thermodynamics

The decrease in enthalpy, which necessarily occurs when a substance produces work without heat supply, is accompanied by a decrease in temperature. Thus, a temperature drop is a necessary condition for the production of work. With the aid of the entropy concept, we can determine the maximum work which can be gained between the two given temperature limits from a given amount of heat.

Consider two containers with the temperatures T_1 and T_2 ($T_1 > T_2$). We take the heat quantity Q_1 from the container with the temperature T_1 and turn it over to a substance which has also the temperature T_1. This substance may convert part of this heat into work, thereby cooling off to the temperature T_2. Then the balance Q_2 of the heat received is given off to the container with the temperature T_2. Both containers may be big enough so that their temperatures remain unchanged. The efficiency, η, of this process is the ratio of the heat converted into work divided by the heat received by the substance. Consequently

$$\eta = \frac{Q_1 - Q_2}{Q_1} \tag{24}$$

The entropy changes ΔS for both containers follow from (22) as

$$\Delta S_1 = \frac{Q_1}{T_1} \quad \text{and} \quad \Delta S_2 = \frac{Q_2}{T_2} \tag{25}$$

and we obtain from (24)

$$\eta = \frac{T_1 \Delta S_1 - T_2 \Delta S_2}{T_1 \Delta S_1}$$

or

$$\eta = 1 - \frac{T_2}{T_1} \times \frac{\Delta S_2}{\Delta S_1} \tag{26}$$

The ratio $\Delta S_2/\Delta S_1$ can be determined by means of the following consideration: We take from the substance in the warmer container just that quantity which contains the heat Q_1 and let this substance directly do the work between the temperatures T_1 and T_2. Then, from the previous section, maximum work is obtained when the process is adiabatic and the entropy remains constant. If the process is accompanied by friction losses, the entropy will increase. The experience shows that the maximum work which can be gained between two temperatures is always the same, no matter by which process it is obtained. Then, this maximum work can depend only on these temperature limits and must in particular be independent of the substance which undergoes the change of state. This experience has been adopted as a universal principle of physics and is called the *Second Law of Thermodynamics*.

According to this law, the maximum amount of work must be the same, whether the heat is transferred from the first container to the working substance and from there to the second container, or the substance in the first container does the work directly. Then, also in the first case, the entropy increases if a friction loss exists or the entropy remains unchanged if the maximum

work is obtained. Consequently, we have in equation (26):

for a change of state with friction: $\Delta S_2 > \Delta S_1$
for a change of state without losses: $\Delta S_2 = \Delta S_1$

Thus, the maximum efficiency for the conversion of heat into work is

$$\eta_{ad} = \frac{T_1 - T_2}{T_1} \qquad (27)$$

This relation states that only a part of the heat available at the initial temperature can be transformed into work, while the balance remains as heat in the substance and is useless for the purpose of producing work. The efficiency, however, is greater, the higher the temperature T_1 is.

While the First Law excluded only the possibility of producing work without consuming some other kind of energy, the Second Law states that the production of work is always accompanied by a transport of heat from a higher to a lower temperature, in addition to the heat required to produce this work. A process in which work would be produced only at the expense of an equivalent amount of heat or energy without further changes in the system is referred to as "perpetual motion of second kind." The Second Law of Thermodynamics states that such a process is impossible.

As a consequence of this law, the vast energy of our surroundings has no value with respect to the production of work, since no temperature interval exists in which it could be made available. Furthermore, all actual changes of state are accompanied by friction losses. Thus, in actual changes, the entropy increases and the available work is less than the maximum work.

Cycle Processes

Heat engines work on the principle that a substance does work of expansion, and is hereafter, by adding of heat, returned to the initial condition whence it resumes the same cycle again. It can be concluded from the previous section that the efficiency of a cycle process equals the maximum efficiency in equation (27), if the total entropy of all systems taking part in the cycle returns to its initial value after each cycle. Since the working substance returns to its initial condition, its entropy resumes, after the cycle, its initial value. Not so the "containers," or whatever takes their place as sources of heat. They undergo a permanent change of state and, consequently, of entropy. Thus, the condition for the maximum efficiency is that the decrease in the entropy of the warmer container equals the increase in the entropy of the cooler container.

This condition is fulfilled when the process traverses equilibrium states only, and when all heat is transferred to the substance without temperature drop at the highest temperature of the cycle and when all heat is given off by the substance without temperature drop at the lowest temperature of the cycle. Various processes working in this manner can be devised. The first to be investigated was the Carnot cycle which consists of subsequent isothermal and adiabatic processes.

Reversibility

Any process which ends with the initial value of the total entropy of a system produces exactly as much work as is necessary to bring the system back to its original state. Such a process is called *reversible*. Not all these processes are *directly reversible* by making the system traverse all intermediate states in reversed sequence. But it is always possible to find some other process through which the system can return into the initial condition without expending any additional work. The process described in the section entitled "*The Second Law of Thermodynamics*" is directly reversible. The adiabatic work together with the heat given off to the cooler container is sufficient to compress the substance to its original volume and to restore to the warmer container the heat previously transferred to the substance. Thus, in the reversion of this process, heat is being transferred from a lower temperature to a higher temperature. This is, however, only possible at the expense of work produced in a previous process. As a consequence of the Second Law, heat cannot flow by itself from a lower to a higher temperature.

If the total entropy of a system increases during a change of state, the work produced is not sufficient to restore the original state of the system and the process is *irreversible*. The work, Z, lost due to the irreversibility is obtained in the following manner:

Compare a reversible process with an irreversible process, both between the temperatures T_1 and T_2. The initial value of entropy is s_1. The final value of entropy, for the reversible process, is again s_1, but for the irreversible process the entropy assumes the higher value s_2. Then the work lost is the difference in the heat quantities given off in the irreversible and the reversible process, i.e.,

$$Z = T_2(s_2 - s_1) = T_2 \Delta s$$

This loss is smaller than the amount of heat created which, according to (22), is $\int_1^2 T\,ds$. Part of this heat is immediately consumed for additional work, but the greater part remains in the substance and is unable to do work when the substance reaches the temperature T_2.

When the irreversible change of state proceeds between the same pressure limits as the respective adiabatic process, the former ends at the higher temperature T_{irr}. In this case, the heat due to transformation of work still has the potential ability to do the work of adiabatic expansion from T_{irr} to T_2 and the final loss of work is again $T_2(s_2 - s_1)$. A limiting case of the irreversible change of state is the heat transfer from a reservoir with the higher temperature T_1 to a reservoir with the lower temperature T_2 in a heat exchanger without doing work and without changing the temperatures of both reservoirs. The amount of work lost due to conduction of heat is obviously again $T_2(s_2 - s_1)$, where s_1 and s_2 are the sums of the entropies of both reservoirs in the intial and final state, respectively.

If the adiabatic enthalpy interval between the temperatures T_1 and T_2 is Δh, the degree of irreversibility is given as

$$\zeta = \frac{Z}{\Delta h} = T_2 \frac{\Delta s}{\Delta h}$$

These few examples may illustrate the importance of the First and Second Laws of Thermodynamics for the investigation of thermal processes.

STEAM ENGINEERING ABROAD

As reported in the foreign technical press

Brown Boveri Turbines

The *Brown Boveri Review* of June 1940 surveys the development of steam turbines built by that well-known Swiss company during the last forty years, which serves as a basis for interesting comparison with turbine development in the United States. The number, types and aggregate capacities of the several types of Brown Boveri units built or ordered, for stationary service, up to December 31, 1939 are as follows:

Type	Number	Total Capacity in Kw
Three-cylinder turbines	102	2,500,245
Two-cylinder turbines	192	2,229,700
Single-cylinder turbines for outputs above 10,000 kw	172	2,179,050
Single-cylinder turbines for outputs below 10,000 kw	2720	5,936,528
High-pressure turbines for pressures above 710 lb and temperatures over 750 F	90	1,270,800
Extraction turbines	421	948,295
Back-pressure turbines	717	911,233
Mixed-pressure turbines	60	131,090

NOTE: The total number of machines and the total capacity do not correspond with the sum of the above eight items in each column, inasmuch as some of the turbines are included in more than one category.

It will be noted that while the number of back-pressure and extraction machines is large, the number and aggregate capacity of mixed-pressure turbines is relatively small. Also, one might expect a greater number for steam conditions exceeding 710 lb per sq in. and 750 F. The highest pressure machine included is one of 36,000 kw that has been operating for the last eight years at 1725 lb per sq in., 935 F at the plant of the Witkowitz Steam Coal Company in Moravia.

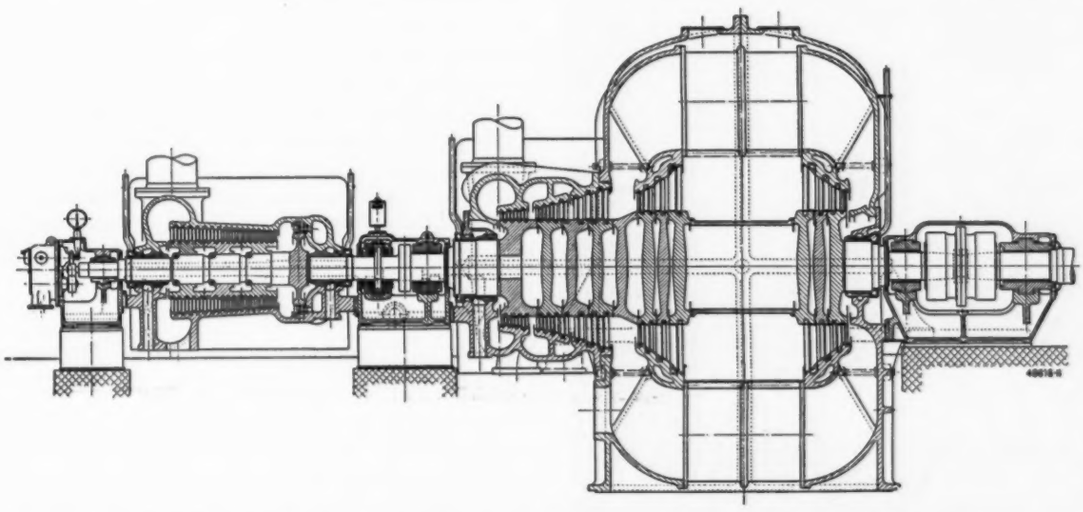
The article points out that the multi-cylinder type offers certain advantages as to higher blade efficiency, as it permits the expansion of steam to take place in a larger number of stages than is possible in a single cylinder and thus makes for a more favorable "Parsons Number." However, in many cases where large units were to be installed in existing stations, space limitations have made it necessary to resort to single-cylinder machines. The upper limit for the latter type is placed at 100,000 kw, 3000 rpm.

More recently, research in blade design has made it possible to build two-cylinder machines with efficiencies comparable to those of the three-cylinder type. Three such condensing turbines of 50,000 kw, at 3000 rpm were built during 1938 and 1939 and are represented by the accompanying cross-section.

The opinion is expressed that, where pressures of 1400 to 1850 lb per sq in. and steam temperatures of 840 to 935 F are involved, intermediate reheating is indispensable. For such high-pressure plants with reheating, the three-cylinder machine is advocated; as this type permits the high-pressure steam to expand in one separate cylinder to that pressure at which reheating takes place, whereas the remaining heat drop available between reheating and the condenser would be in excess of that which can be economically used in one cylinder only.

Protection of Equipment Against Gas Attack

According to *Engineering* (London) of August 30, the British Electricity Commissioners are circulating to the various power companies a report covering methods of protecting power equipment against contamination which might result from gas attacks. Gross contamination, it is pointed out, may alter the electrical behavior of a plant, but the principal danger is from contact between the liquid, as mustard gas, and the personnel; while heat may assist the dissemination of poisonous vapor. A list of suitable solvents from the various gases



Two-cylinder tandem condensing turbine designed for 50,000 kw at 3000 rpm

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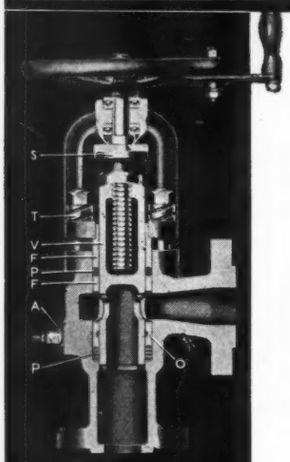

Yarway Seatless Blow-off Valve. Operation: After Valve is closed, shoulder S on plunger V contacts with upper follower gland F, forcing it down into body and compressing packing P above and below port. Annular groove O connects with Alemite fitting A for lubricating plunger and packing. Yoke springs T maintain continuous pressure through follower gland F on packing rings P.

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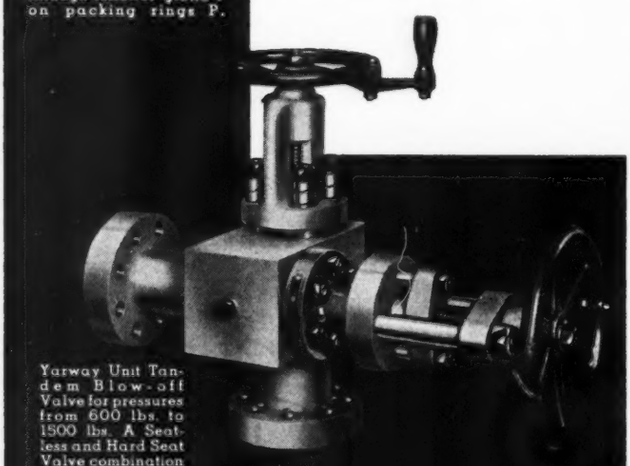


Yarway Unit Tandem Blow-off Valve for pressures from 600 lbs. to 1500 lbs. A Seatless and Hard Seat Valve combination using a common forged steel body.

YARWAY BLOW-OFF VALVES

is given, and the procedure has been worked out for dealing with such equipment as switchboards, switchgear, motor starters, cables, insulators, etc. In selecting a decontaminating solvent care must be taken to avoid using anything that might have a deleterious effect on the equipment. Light oils, for instance, are fairly safe.

Attention is called to the fact that materials penetrable by mustard gas are of two types; those in which there is penetration by creeping along the pores or fibers and those in which the gas acts by dissolving the material. In the first case the gas is free to evaporate and can also be affected by the slow destructive effect of atmospheric moisture; whereas in the second, the gas will be retained unchanged for a long time and only complete destruction of the contaminating agent can be considered satisfactory.

Fouling of Air Heaters

The September issue of *Engineering and Boiler House Review* (London) discusses the performance of air preheaters with respect to fouling and corrosion, as affected by design and operating conditions. "Troubles of this kind," says the author, "in many cases increase as the metal temperature decreases below 300 F above which troubles are only slight. A further determining effect is often the amount of dust carried by the flue gases and the sulphur content of the coal. The dewpoint of flue gases containing traces of sulphuric acid vapor is higher in comparison with the dewpoint when only water vapor is present, and this is frequently the explanation of corrosion even when the flue gas temperature is well above that of the dewpoint of water vapor."

Tests are cited, with reference to several large pulverized-coal installations, indicating that the fly ash is usually lower in sulphur content than that from stoker-fired boilers and that the corresponding sulphuric acid vapor concentration is about 70 per cent less.

With the plate-type heater, fouling generally commences at the extreme air-inlet edge of the plates, a point at which more plate area is swept by the cold air than by the hot gases, thus causing low temperature and consequent clogging. In tubular heaters the shape of the tubes is a factor in fouling and corrosion. This has been shown by experience with vertical heaters in cases where the tubes are bent at the bottom and top to enter the tube plates at an angle. In some such cases serious plugging was found at the bottom header and also loss of metal, it being necessary to drill out the tubes from time to time. Heaters with straight tubes, however, working under practically similar conditions gave no such trouble.

Regarding the cleaning of air heaters, the author's experience has indicated that soot blowers have, in general, been effective in removing deposits from the gas side, although washing has in many cases resulted in increased life of the elements.

Sulphur Dioxide, a Cause of Blade Corrosion

Dark brown or black deposits on turbine blades, accompanied by corrosion, as reported in a number of cases in Germany, led to laboratory investigations which are reviewed by F. Lüben in *Die Wärme*, Vol. 63, p. 136. These studies pointed to leakage steam, containing sul-

phur dioxide or sulphureted hydrogen, as the corrosive agent, although the steam was free from salts. The presence of sulphur dioxide was attributed to the degasification of the feedwater.

In the tests the steam was produced from distilled water and small amounts of sulphur dioxide added. Blades having a high chromium content (13 to 18 per cent) resisted attack; chrome-molybdenum steels (1 per cent Cr and 0.8 per cent Mo) were affected to some extent and nickel steel (5 per cent Ni) to a much greater degree; whereas the non-alloyed steels were rapidly attacked. Tests with 0.005 per cent sulphur dioxide in the distilled water produced severe corrosion within less than two weeks. It is pointed out that although the amount of sulphur compounds in the feedwater may be very small the concentration in the boiler water may be considerable and sufficient to cause trouble with the turbine blading.

Temperature Measurement of Gas Turbine Runners

Dr. H. H. Berg, in *VDI Zeitschrift*, Vol. 84, No. 19, writes that in the German Experimental Station for Aeronautics, two methods were developed for making temperature measurements on gas turbine runners. One method employed a radiation pyrometer to observe temperatures of certain chosen runners; the other employed thermocouples applied to the rotating runners for studying the temperature distribution therein.

The measuring range for the usual commercial radiation pyrometer does not include temperatures of from 50 to 600 C (122 to 1112 F) occurring in the buckets and wheel disks of exhaust gas turbines. A new apparatus was developed as illustrated in Fig. 1.

The radiation emanating from a chosen point *a* is reflected by concave mirror *h* onto a thermopile *f* through

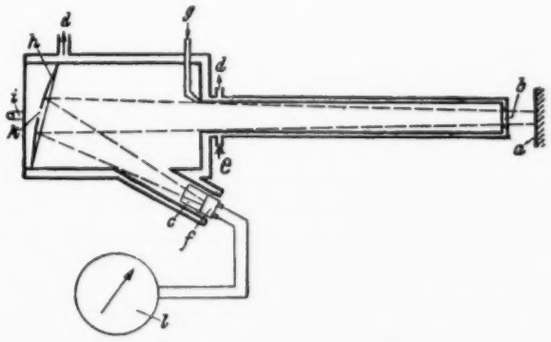
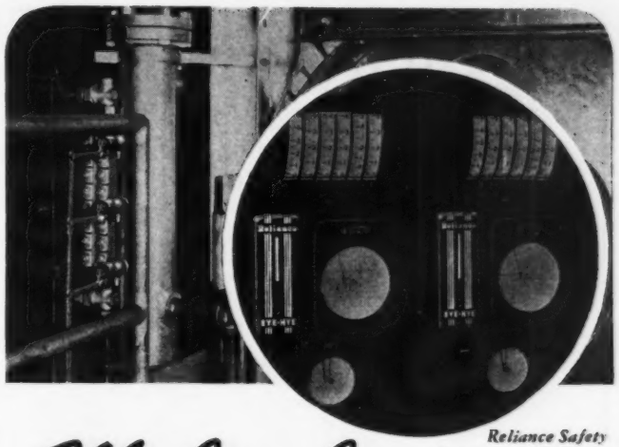


Fig. 1—Arrangement of radiation pyrometer

a object of measurement
b, *c* apertures
d cooling water efflux
e cooling water influx
f thermopile
g air tube
h convex mirror
i peep hole through the housing
k opening in the convex mirror
l mirror galvanometer

an aperture *c*. The thermal value may then be read by a galvanometer *l*. The junctions of the serially arranged thermocouples of constantan-manganin are aligned, there being eighteen junctions within a length of 6 mm. The sensitivity of the apparatus requires special precautions to avoid extraneous heat influxes, since tempera-



Reliance Safety Team installation in Colorado State Capitol, Denver, Colorado.

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Boiler Water
EYE LEVEL GAGE
No water carry-over • No burned boilers

The McNeill Gage

Note the clear line of demarcation of the black indicating fluid by which the gage may be read at a wide angle range.

For stationary or marine service—pressures up to 2000 lbs.

OUTSTANDING FEATURES

1 Water from the boiler or the connecting pipes to the gage never contacts the indicating glass so that it always remains clear and bright inside. It brings the *water-level down to eye-level* of the operator.

2 Being entirely hydrostatic in its action it cannot be less safe than the conventional water glass located at the water line at top of the boiler. That it is operative may be checked at any time by the simple expedient of blowing down the water column to which it is connected.

3 *It is more accurate than the water glass connected at the water line on the boiler*, because it may be calibrated to be correct for the weight of the boiler water at its operating temperature. This high degree of accuracy is not possible with regular water column glass because of the inevitable difference in temperature between the water in the glass and that in the boiler.

4 The indicating glass does not erode nor deteriorate with use; maintenance cost is therefore practically nil.

5 Safety of operation is greatly increased by having the knowledge of the water level unmistakably before the operator who controls the fire.

We also manufacture the Eclipse Smoke Indicator Systems of all types and arrangements—periscopes, photo-electric and both in combination. Write for bulletins on McNeill Products.

T. W. McNEILL Engineering Equipment Co.

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ture variations of the housing and observation tube, observed during preliminary tests, led to errors. These may be eliminated by suitable water cooling. The temperature balance of the thermopile should occur within two seconds. The construction of a suitable concave mirror involved some difficulties since aggressive gases from the turbine could pass into the apparatus. By blowing air through tube *g* this difficulty was completely avoided. There was also some danger of a change in the reflecting power of the mirror and a resultant change in the value of the reflected radiation of the different metal deposits which were tried for the mirror. Rhodium applied in a vacuum finally proved to be superior to gold, silver, aluminum, etc., when considering its capacity to maintain the value of the reflected radiation as well as its stability.

The apparatus was calibrated by measurements on a heated bucket segment, the temperature of which was measured by thermocouples.

In practice, measurements of temperatures taken at particular points of turbine runners for investigating

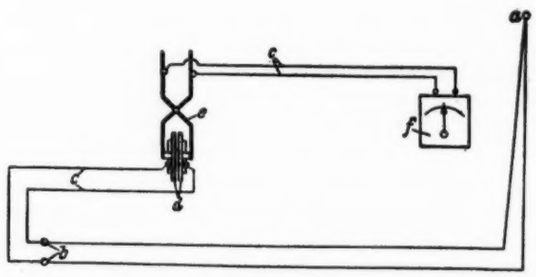


Fig. 2—Arrangement of measuring apparatus with thermocouples applied to rotating runners

a point of measurement
b cold junction
c copper wires
d contact disk
e contact pincers
f multivoltmeter

their shape and strength can be taken during operation only by means of thermocouples attached to rotating runners. Here difficulties arise, because of the high speeds involved in exhaust gas turbines, in establishing contacts for the current flow either by immersion in mercury or by spring-loaded axial or radial brushes. A set of pincers was finally developed consisting of copper brushes which were lightly pressed by hand against the sides of two disks insulated from each other. The pressure is exerted only while measurements are being made to avoid overheating the brushes and is continued until the galvanometer ceases to rise. This method proved satisfactory in preliminary tests for speeds up to 22,000 rpm.

A test runner was provided with a series of nickel-nickel chrome thermocouples at points selected as most important. Wires *c*, Fig. 2, were led through tubes of steatite having two holes, gathered into a central bore and led to contact carrier *d*. Pincers *e* were connected to a measuring device *f*. The influence of the housing temperature and the heating of the contacts upon the series of thermocouples must be given consideration. The installation was continuously checked by resistance measurements.

Some Further Power Statistics

THE Federal Power Commission in a report just issued as a "Supplement to Electric Power Statistics for the Year 1939" gives figures on installed capacity, electric consumption per capita, fuel used and economy of fuel burned, as applying to plants generating electricity for public use. These figures are broken down for the several geographic divisions of the United States; also data as to production by different classes of ownership and the movement of energy across state boundaries are included.

Table 1 compiled in abbreviated form from the more extensive data in the report shows the total installed capacity, and that per thousand population, as well as the kilowatt-hours produced per capita from 1920 through 1939. It will be noted that the greatest per capita consumption of electricity appears in the Pacific and Mountain divisions, a situation that has obtained over the entire twenty-year period, although the installed capacity in these regions is very much less than in most other sections. In all cases there has been a steady increase in the per capita use of electricity which has more than doubled during this period.

TABLE 1—CONSUMPTION PER CAPITA AND CAPACITY PER 1000 POPULATION

	Kilowatt-Hours per Capita					Kilowatts per 1000 Population					Installed Capacity, Kw, 1939
	1920	1925	1930	1935	1939	1920	1925	1930	1935	1939	
United States	410	572	771	772	994	136	205	277	283	307	40,317,924
New England	444	602	763	791	957	210	281	355	339	347	3,028,280
Mid. Atlantic	555	750	957	951	1182	171	256	324	344	350	9,746,991
E. N. Central	463	668	876	892	1144	148	229	312	313	346	9,069,488
W. N. Central	254	329	450	481	560	95	140	178	196	225	3,157,538
S. Atlantic	279	421	634	650	867	115	173	269	259	277	4,843,202
E. S. Central	163	274	370	373	640	58	116	162	158	184	2,001,627
W. S. Central	121	195	415	384	533	41	72	131	140	156	2,041,071
Mountain	774	884	999	1152	1947	213	235	309	322	560	2,156,800
Pacific	971	1228	1553	1520	1620	249	366	463	475	476	4,272,927

The same holds true for the installed capacity which is given, with reference to type of prime mover, in Table 2.

TABLE 2—INSTALLED CAPACITY BY TYPE OF PRIME MOVER FOR ALL CLASSES OF OWNERSHIP IN U. S., KILOWATTS

Year	Total	Steam	Hydro	Internal Combustion	Steam Per Cent of Total
1920	14,372,009	10,490,944	3,786,595	94,470	72.9
1925	23,512,000	17,166,846	6,158,849	186,305	73.06
1930	34,055,319	24,695,862	8,941,020	418,437	72.5
1935	36,074,442	25,708,209	9,795,138	571,095	71.3
1939	40,317,924	28,046,948	11,415,165	855,811	69.5

The figure for hydro capacity has been further increased, as of September 16, 1940, by 3.1 per cent due to the placing in service of several large Federal projects. While corresponding figures on the increase in steam capacity up to this date are not available, it is reasonable to conclude that current activity in this branch of the field has kept pace with or probably exceeded the increase in hydro capacity.

TABLE 3—CAPACITY AND PER CENT OUTPUT BY CLASS OF OWNERSHIP

	Privately Owned			Publicly Owned		
	Capacity Kilowatts	Per Cent	Output, Per Cent	Capacity Kilowatts	Per Cent	Output, Per Cent
1920	13,681,000	95.2	96.1	691,000	4.8	3.9
1925	22,085,000	93.9	95.8	1,427,000	6.1	4.2
1930	31,956,000	93.8	94.7	2,099,000	6.2	5.3
1935	33,459,000	92.7	93.9	2,615,000	7.3	6.1
1939	35,363,000	87.7	90.4	4,955,000	12.3	9.6

From Table 3 it will be noted that, despite a steady increase in the capacity of publicly owned plants since 1920, until they now account for 12.3 per cent of the capacity, their output is only 9.6 per cent of the total. In other words, the percentage ratio of output to capacity is 1.03 in the case of privately owned plants compared with 0.78 for those publicly owned.

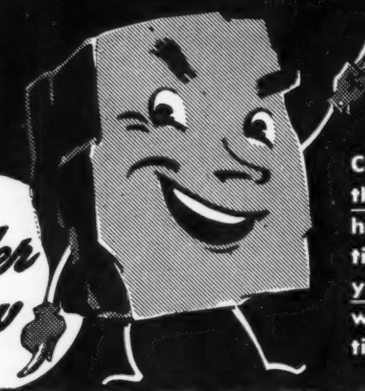
With reference to the fuel consumed by steam stations during 1939, as shown in Table 4, there is wide variation in the fuel per kilowatt-hour and in the Btu per kilowatt-hour average station heat rates for different sections of the country. This variation may be attributed to several factors, including quality of fuel available and its cost which determines largely the refinements that go into the plant. The best showing with bituminous coal is made in the Middle Atlantic, New England and East North Central States, whereas the Middle Atlantic States have the best record with oil and the East North Central States that with gas. The average figure for the United States, as a whole, of 1.35 lb per kwhr with bituminous coal is in marked contrast with that of 3.39 for 1920, and may be taken as a measure of the improvements in design and operating practice over the past twenty years.

As will be noted from the tabulation, the total tonnage for anthracite and for lignite is relatively small, compared with the other fuels.

TABLE 4—FUEL CONSUMED BY ELECTRIC GENERATING STATIONS DURING 1939

	Bituminous Coal			Anthracite			Lignite			Oil			Gas		
	1000 Tons	Lb/ Kwh	Btu/ Kwh	1000 Tons	Lb/ Kwh	Btu/ Kwh	1000 Tons	Lb/ Kwh	Btu/ Kwh	1000 Bbl	Kwh/ Bbl	Btu/ Kwh	Million Cu Ft	Cu Ft/ Kwh	Btu/ Kwh
United States	42,441	1.35	17,054	2,244	1.89	21,039	1,538	2.58	19,222	17,423	423	14,869	191,131	16.2	16,944
New England	2,237	1.25	17,758	3	5.60	82,242				5,282	359	18,058			
Mid. Atlantic	12,231	1.21	16,827	2,233	1.89	20,979				5,025	552	11,458	4,452	20.5	20,887
E. N. Central	17,779	1.38	16,089							334	448	13,314	16,003	13.6	14,041
W. N. Central	2,729	1.72	19,324				468	3.84	26,670	1,236	416	14,428	41,571	20.4	21,080
S. Atlantic	5,306	1.31	17,887	5	1.82	20,163				3,541	359	17,531	3,681	14.7	14,511
E. S. Central	1,517	1.98	24,110							91	345	19,402	7,458	21.3	19,783
W. S. Central	239	1.78	21,068	3	4.16	55,572	687	2.42	16,713	679	389	15,388	85,301	15.2	16,041
Mountain	393	2.31	25,165				383	2.01	18,536	630	364	16,882	9,503	18.8	19,074
Pacific	10	1.50	18,696							605	412	15,271	23,161	14.3	16,611

STAY ON TOP OF STEAM DEMAND ALL THE TIME!



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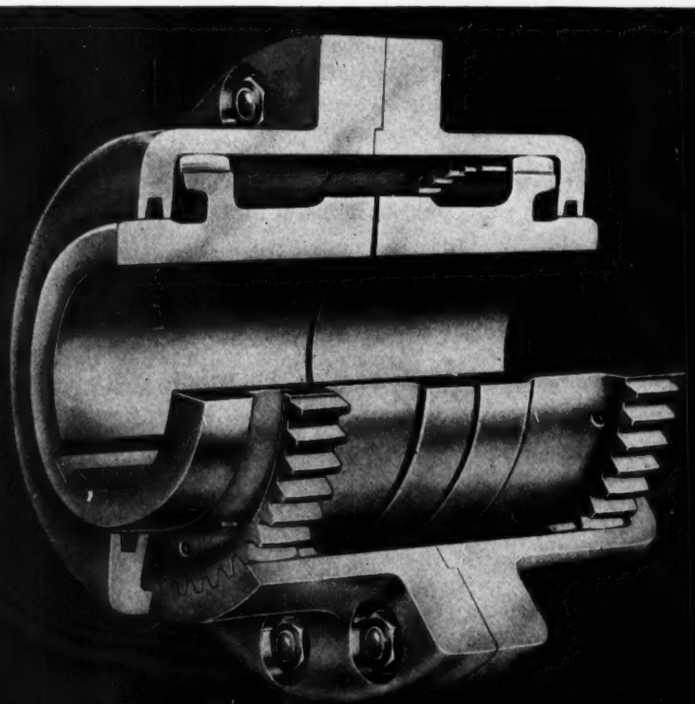
POOLE



A COPY OF CATALOG GIVING FULL DESCRIPTION AND ENGINEERING DATA SENT UPON REQUEST.

FLEXIBLE COUPLINGS

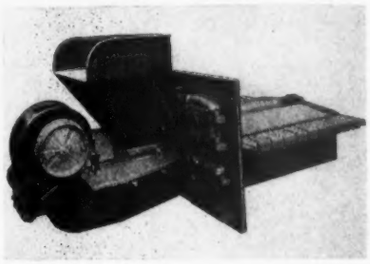
POOLE FOUNDRY & MACHINE COMPANY WOODBERRY, BALTIMORE, MD.

NEW EQUIPMENT

Low-Ram Stoker Unit

To meet the demand for a small ram-feed underfeed stoker, Combustion Engineering Company has brought out the "C-E Low-Ram Stoker Unit," designed to burn either coking or non-coking bituminous coals under boilers up to 250 horsepower.

This is a low-set, electrically-driven unit with stationary grate bars and cantilever-type dump grates, the body of the stoker being only 16 in. high. A forced-draft



fan, fitted with vortex-type inlet damper and directy connected to the stoker-drive motor is incorporated as an integral part of the unit. The motor is of the constant-speed type, mounted directly on the gear case and connected to the reduction-gear train by an enclosed silent chain, and a safety release coupling protects the drive mechanism against overload resulting from any obstruction in the feed.

A cast-steel connecting rod connects the drive crank to the crosshead operating block which actuates the coal-feed ram; and each stroke is a full stroke, the rate of feed being controlled by varying the period of rest between consecutive strokes. This is accomplished by a latch connection between the coal-feed ram and the crosshead operating block.

The main ram feeds coal from the hopper to a one-piece retort extending the full length of the furnace section; and the rear of the retort, although supported by the rear end frame, is free to float to allow for expansion. Adjustable auxiliary pushers, designed to distribute the coal evenly from front to rear of the retort, are bolted directly to the auxiliary pusher bar which extends the full length of the retort.

Block and Pipe Insulation

A new 1500-deg insulating material called L-W Superex has recently been introduced by Johns-Manville. Furnished in both block and pipe covering form, this new material is said to represent an improvement in conductivity and strength for an insulation in the service temperature range above 600 F. It is offered for use generally in stationary and marine power plant equipment and piping, the blocks also being suitable for use in industrial furnaces, high temperature mains, flues and stacks, where the insulation will be subjected to temperatures between 600 and 1500 F. The sectional form is intended for piping and headers within the same temperature range.

This new insulation is of the molded diatomaceous silica type, but it is exceptionally light in weight for a high temperature material, weighing only 20 lb per cu ft. The blocks are furnished 3, 6, 9 and 12 in. wide in standard lengths of 18 and 36 in. and in thicknesses from 1 to 4 in. Curved blocks are also available. The pipe insulation is supplied, to fit standard pipe sizes, in sections or segments 3 ft long and up to $2^1/_2$ in. thick.

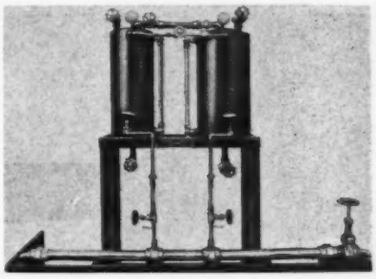
Improved Proportioning Feeder

D. W. Haering & Company, Inc. announces a new and improved Model "B" feeder employing the fluid-piston principle for proportioning liquids into liquids or gases. Operating on the pressure difference between pitot tubes, these units operate without the use of motors, meters or pumps.

Improvements in the new Model "B" feeder include the use of flexible steel tubing on pitot tubes and cross lines to take up the stress and shock of water hammer or slight misalignments due to curling of welded connections. The check valve is now installed on the needle valve line where it prevents reagent backing into the needle valve line and is not subject to clogging or corrosion, thus assuring perfect check valve performance and better drop feed indication.

Both gage glasses are installed on the inside of the units facing each other, which protects gages from accidental damage and reduces the hazard from gage glass breakage.

Overall height of fluid compartments has been increased to provide greater capacity and safety from red oil losses. The needle



valve line has been brought out in front of the tanks reducing friction loss and gas binding resulting in greater sensitivity and accuracy.

Remote Pneumatic Transmission Systems

To correlate temperature, pressure, flow or liquid level on a centralized panel, or in a control room remote from the point of measurement, Taylor Instrument Companies offers a new remote pneumatic transmission system. It utilizes standard instruments and may consist of one or two transmitters connected into one or more receivers of the indicating, recording or controlling types. Air pressure is the transmitting medium, and is said to afford a maximum time lag, in recording, of 1 sec per 100 ft of connecting tube.

The systems are reported to be accurate, to eliminate electrical hazards and to function continuously.

Changing Fuel?

IF changing fuel, your baffles should be redesigned to suit new requirements. Beco-Turner baffles are built to any shape or contour that will give maximum performance. Readily installed in connection with new or existing boilers. Let us submit our recommendations covering proper baffles for your boilers.

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EFFICIENT!

Beco-Turner baffles are gas tight. As shown opposite, the tubes are tightly mortared into the self-hardening refractory material of which these baffles are constructed. Beco-Turner baffles remain gas tight because their patented expansion joints prevent cracks and leaks.

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EQUIPMENT SALES

Boiler, Stoker, Pulverized Fuel

as reported by equipment manufacturers to the Department of Commerce, Bureau of the Census

Boiler Sales

	1940 Water Tube		1939 Water Tube		1940 Fire Tube		1939 Fire Tube	
	No.	Sq Ft*	No.	Sq Ft*	No.	Sq Ft	No.	Sq Ft
Jan.	62	285,042	75	427,658	51	68,639	50	64,511
Feb.	54	386,356	70	340,559	47	51,474	45	58,028
Mar.	56	438,980	98	484,220	51	58,529	58	54,752
Apr.	89	476,135	62	301,875	56	50,356	36	42,177
May	101	663,721	104	447,722	75	84,094	74	96,037
June	150	814,210	99	538,736	110	122,026	52	58,793
July	111	632,373	88	345,834	89	128,784	59	66,595
Aug.	118	685,212	88	426,206	90	108,680	52	55,714
Jan.-Aug., Inclusive..	741	4,382,029	684	3,312,810	569	672,582	426	496,607

* Includes water wall heating surface.

Mechanical Stoker Sales†

	1940 Water Tube		1939 Water Tube		1940 Fire Tube		1939 Fire Tube	
	No.	Hp	No.	Hp	No.	Hp	No.	Hp
Jan.	24	10,770	44	17,067	104	14,745	145	17,842
Feb.	31	10,729	46	20,715	118	17,862	140	18,217
May	35	17,460	46	19,068	76	12,717	122	15,743
Apr.	36	14,554	50	18,888	89	15,123	114	13,652
May	73	30,930	62	29,245	88	11,402	153	20,010
June	65	16,772	83	34,618	152	21,636	184	21,801
Jan.-June, Inclusive..	264	101,215	331	139,601	627	93,485	858	107,265

† Capacity over 300 lb of coal per hr.

Pulverized Sales

	1940 Water Tube			1939 Water Tube			1940 Fire Tube			1939 Fire Tube		
	No.		Lb	No.		Lb	No.		Lb	No.		Lb
	N.‡	E.‡	Coal/Hr	N.‡	E.‡	Coal/Hr	N.‡	E.‡	Coal/Hr	N.‡	E.‡	Coal/Hr
Jan.	10	—	214,250	10	—	79,000	1	—	600	—	—	—
Feb.	15	1	186,935	7	—	89,600	1	2	2,800	—	—	—
Mar.	18	1	331,800	27	—	501,560	—	—	—	—	—	—
Apr.	26	5	270,500	8	—	155,050	—	—	—	—	—	—
May	30	5	447,450	19	—	401,800	—	—	—	—	3	1,800
June	21	2	360,270	16	1	243,230	—	—	—	—	—	—
Jan.-June, Inclusive...	120	14	1,811,205	87	1	1,470,240	2	2	3,400	—	3	1,800

‡ N—New boilers; E—Existing boilers.